INFOMAR Survey Report: CE19_01
Area: Celtic Sea

Marine Institute & Geological Survey Ireland

RV *Celtic Explorer*

September & October 2019

Prepared by Kevin Sheehan & INFOMAR Survey Team

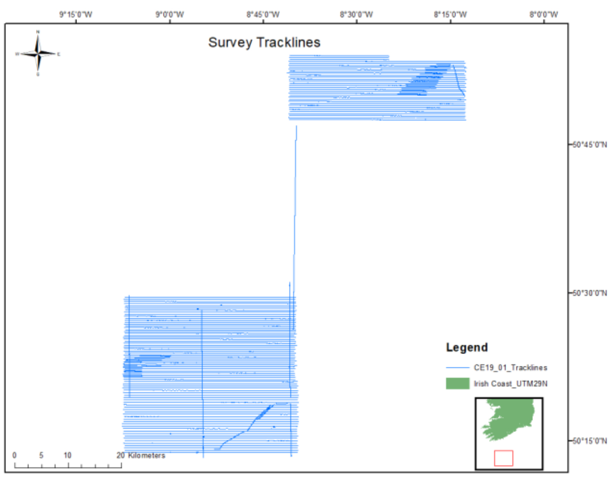
INFOMAR is funded by the Department of Communications, Climate Action and Environment and jointly managed by the Geological Survey Ireland and the Marine Institute

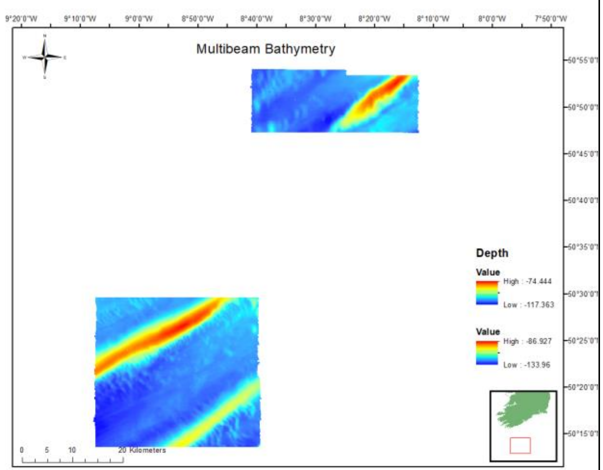
Marine Institute Reference No:	Survey Report: CE19_01

		Signature	Date
Compiled by	Kevin Sheehan	Kevin Sheehan	14/06/2020
Checked	Fabio Sacchetti	Fabio Sacchetti	20/07/2020
Project Managers: Marine Institute & Geological Survey Ireland			

Issue	Change	Date	Description	By	Approved
1		14/06/2020	Final	K. Sheehan	F. Sacchetti

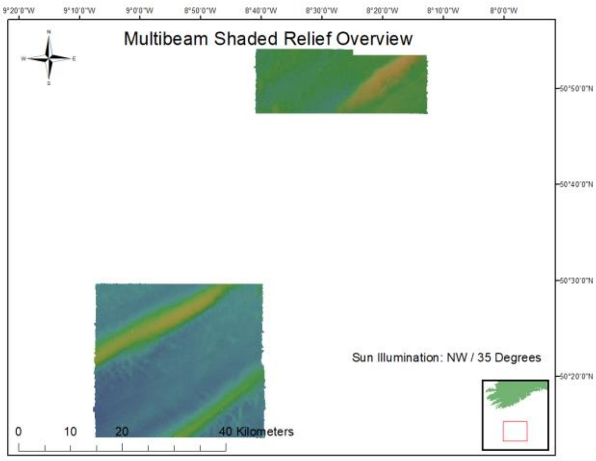
Executive Summary			
Survey Summary			
Survey Vessel:	RV *Celtic Explorer*	**Survey Leg:**	CE19_01
Mobilisation:	Cork	**Demobilisation:**	Cork
Survey Areas:	Celtic Sea	**Start Date:** **End Date:**	21/09/2019 08/10/2019
Northeast Boundary	50º 53.682N -8º 12.806W	**Southwest Boundary**	50º 13.998N -9º 07.251W
UKHO Admiralty	0002 (1:1,500,000) & 1123 (1:500,000)		
Key References	CE19_01 Survey Leg Report & CE19_01 Executive Report		
Equipment Used	EM2040, EM302 & EM1002 multibeams, Echoes 3500 T7 Chirp sub-bottom profiler, EA600 singlebeam, SeaSpy magnetometer, AML MVP200, Valeport SVP Mini, C-Nav 3050 GNSS.		
Survey Statistics			
Minimum Water Depth (VORF LAT):	74 m	**Maximum Water Depth (VORF LAT):**	134 m
Area Covered:	1358 km^2	**Survey Line Kilometres:**	3793 km
Approximate Operational:	65%	**Approximate Downtime :**	21%
Groundtruthing Stations:	0	**Wrecks**	6
H525 forms issues (wrecks)	3	**H102 forms issued (shoals)**	0
Survey Tracklines		**Multibeam Bathymetry**	



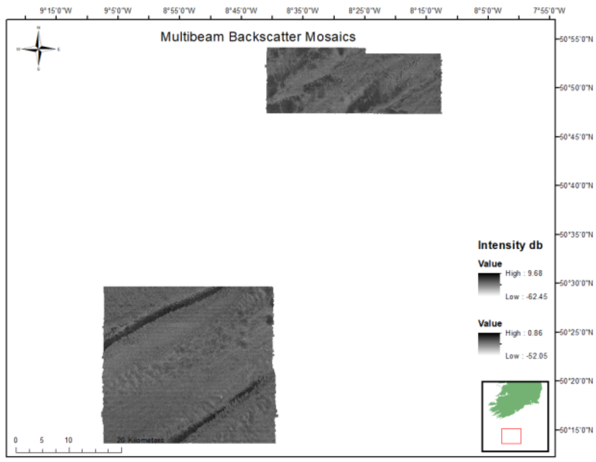


Survey Images

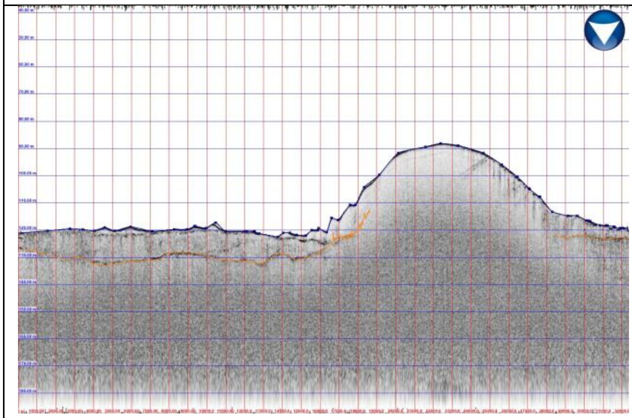
Multibeam Shaded Relief



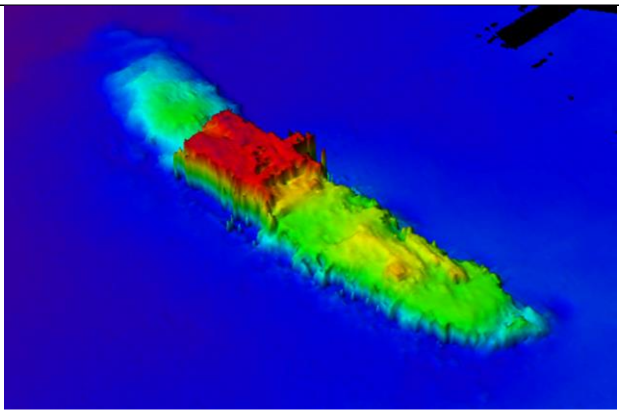
Multibeam Backscatter Mosaic



Sub-Bottom Profiler Data Interpretation



Multibeam Wreck Image



Surveyor Workstation

Survey Statistics

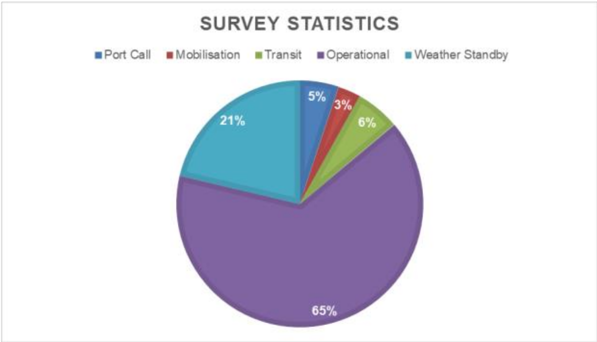


Table of Contents

Table of Figures

Table of Tables

List of Acronyms Used Within This Report

Acronym	Full Name
AML	AML Oceanographic
BEAMS	Benthic Acoustic Mapping Survey Program
BIST	Built-In Self-Test
CTD	Conductivity Temperature Depth
CUBE	Combined Uncertainty and Bathymetry Estimator
DCCAE	Department of Communications, Climate Action & Environment
DGNSS	Differential Global Navigation Satellite Systems
DPR	Daily Progress Report
ETRF	European Terrestrial Reference Frame
ETRS89	European Terrestrial Reference System 1989
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GSI	Geological Survey Ireland
HSE	Health Safety & Environment
HVF	Hips Vessel File
IHO	International Hydrographic Organisation
INFOMAR	INtegrated Mapping FOr the Sustainable Development of Irelands MArine Resource
INSS	Irish National Seabed Survey
LAT	Lowest Astronomical Tide
MBES	Multibeam Echo-Sounder
MVP	Moving Vessel Profiler
MI	Marine Institute
MRU	Motion Reference Unit
NPWS	National Parks & Wildlife Service
PPE	Personal Protective Equipment
PPS	Pulse Per Second
PPP	Precise Point Positioning
PU	Processing Unit
QINSy	Quality Integrated Navigation System
RTG	Real Time Gypsy
RV	Research Vessel
SBP	Sub Bottom Profiler

SBES	Singlebeam Echo Sounder
SIS	Seafloor Information System
SVP	Sound Velocity Profile
TPU	Total Propagated Uncertainty
TTRS	Training Through Research
UKHO	UK Hydrographic Office
UTC	Coordinated Universal Time
VORF	Vertical Offshore Reference Frame
WGS	World Geodetic System

1 Introduction

1.1 Project Overview and Objectives

The Geological Survey Ireland (GSI) and Marine Institute (MI) conducted seabed mapping between 2003 and 2005 under the auspices of the Irish National Seabed Survey (INSS) and from 2006 to present day under the INtegrated mapping FOr the sustainable development of Irelands MArine Resource (INFOMAR) programme. INFOMAR is a joint venture between the GSI and the MI. The programme succeeded the INSS which was one of the largest marine mapping programmes ever undertaken, with a focus on deep water mapping. INFOMAR is funded by the Irish Government through the Department of Communications, Climate Action and Environment (DCCAE).

INFOMAR Phase 1, 2006 to 2015 focused on mapping 26 priority bays and 3 priority areas around Ireland and creating a range of integrated mapping products of the physical, chemical and biological features of the seabed in those areas. INFOMAR Phase 2, 2016 to 2026 intends to map the remainder of Ireland's entire seabed. Figure 1 shows the extent of the mapped area under INSS and INFOMAR and the outstanding areas as of January 2019. Grey have already been mapped, blue and coloured hatched areas are unmapped.

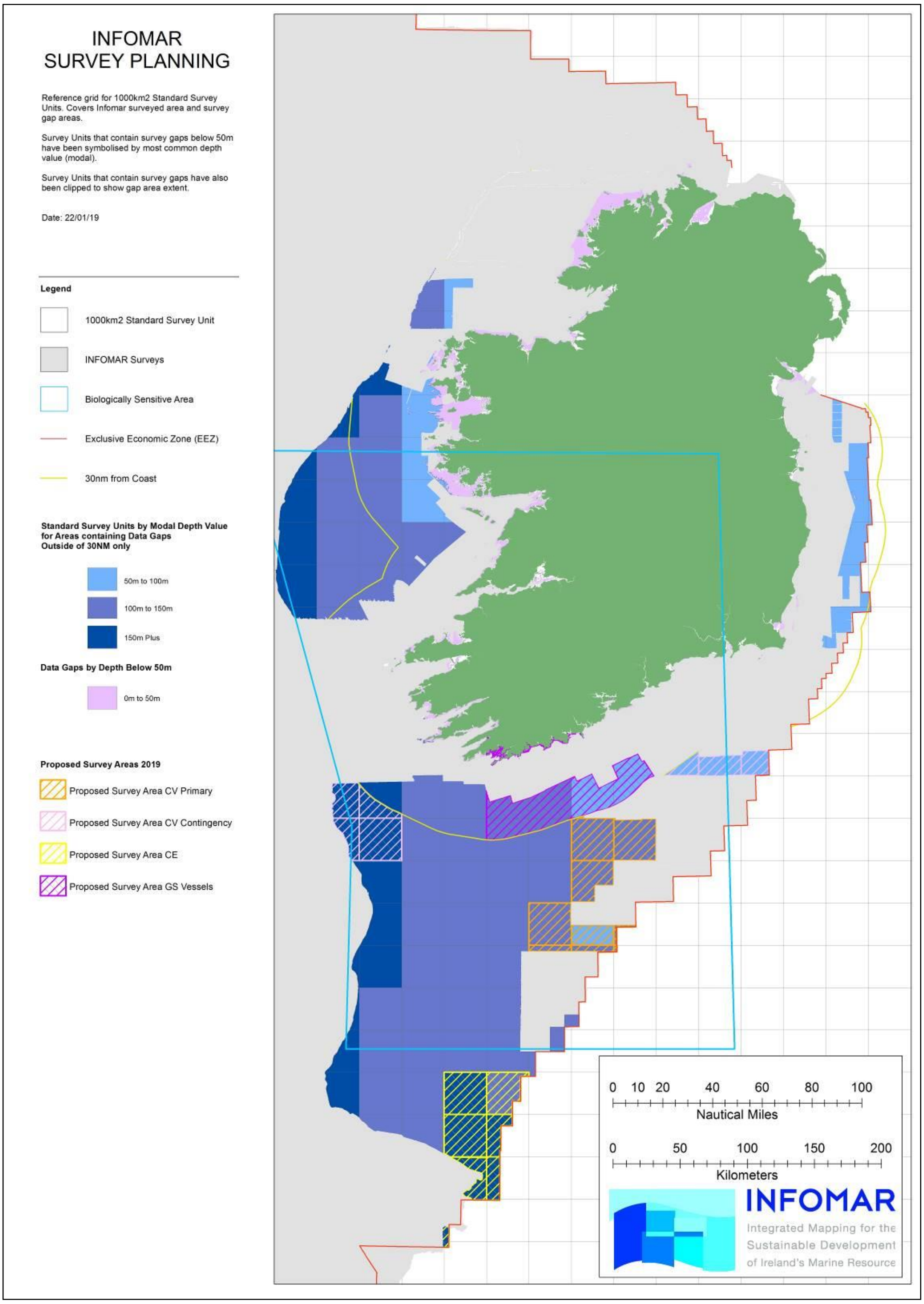


Figure 1: Survey coverage status January 2019.

MI supplied the research vessel RV *Celtic Explorer* and experienced personnel for the survey.

The scientific aims of the survey were to:

(i) Undertake a Multibeam Echo Sounder (MBES) hydrographic survey to International Hydrographic Organisation (IHO) Order 1a in water depths less than 100 metres and Order 2 in depths greater than 100 metres.

(ii) Produce bathymetry, shaded relief and backscatter mosaic products to provide depth, seabed features and seabed hardness/roughness information.

(iii) Acquire Sub Bottom Profiler (SBP) data of the shallow (up to 30 metres) sub seabed to determine the existence of buried objects and ascertain the sub-seabed character.

(iv) Acquire magnetometer data to investigate the sub seabed geology and provide information on manmade seafloor debris.

(v) To map in detail and provide hydrographic wreck reports on any wrecks.

(vi) To acquire multispectral data from the two on board MBES systems to investigate seabed backscatter character.

(vii) To acquire water column data from the EM2040 and EM302 MBES.

(viii) To acquire Moving Vessel Profiler (MVP) data for calibration of the acoustic data and investigation of the thermocline.

(ix) Groundtruth the sedimentary facies evident on the acquired multibeam data.

1.2 Survey Area

Figure 2 shows the designated survey area in yellow hatching. The RV *Celtic Explorer* designated area is located to the south west at the southern end of our unmapped area. The inset image shows the overall shelf coverage to date. Mapped areas are in grey and unmapped in white. The entire area is split into 1000 Km^2 grids, orientated north-south and east-west. The RV *Celtic Explorer* and RV *Celtic Voyager survey* areas are located in the Celtic Sea in sites selected for their strategic fisheries importance.

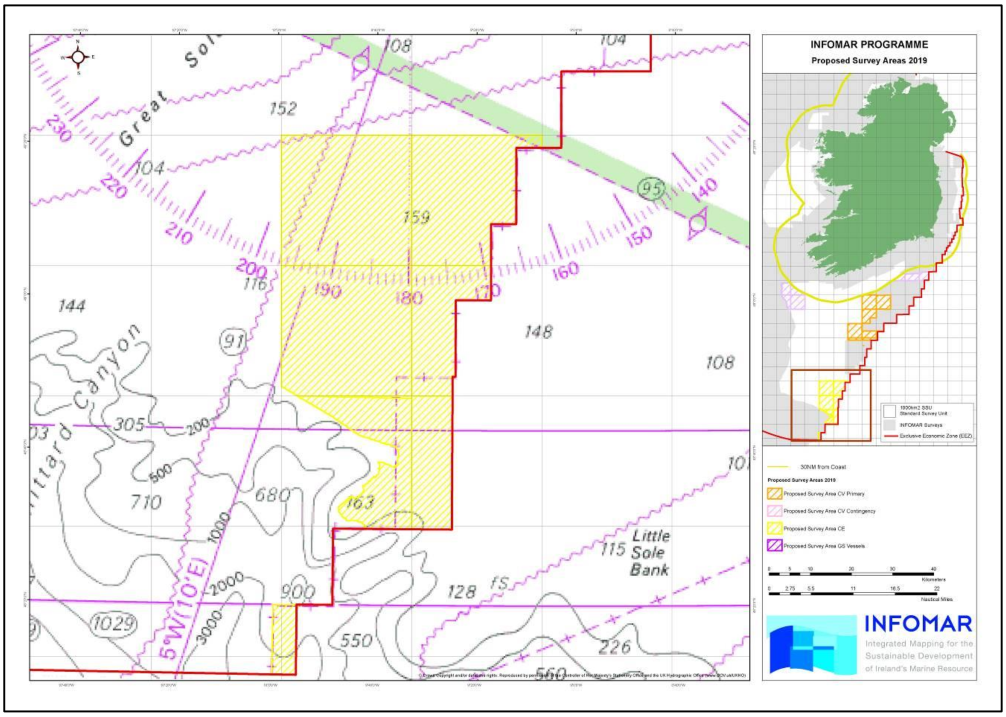


Figure 2: RV *Celtic Explorer* proposed survey areas for 2019.

Two ex-hurricanes with uncertain forecast tracks close to our original survey area necessitated us operating in the proposed RV *Celtic Voyager* 2019 survey area (figure 3). This area had the additional benefit of being closer to port for sheltering options.

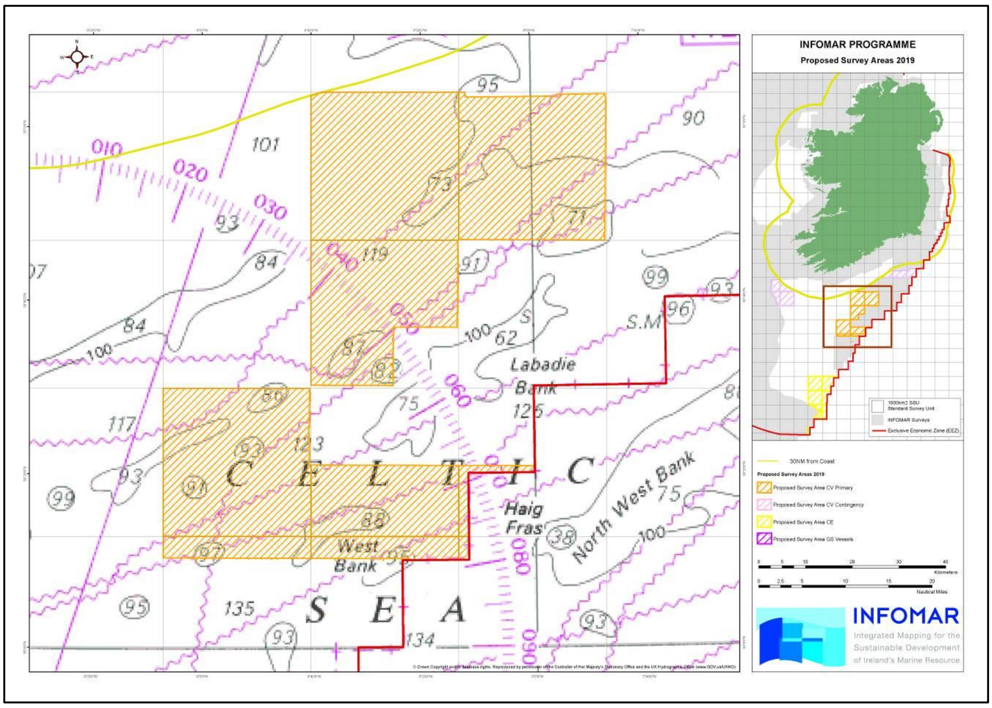


Figure 3: RV *Celtic Explorer* contingency area for 2019.

2 Operations

Mobilisation took place in Cork City on 21st September. Data acquisition took place between 22rd September and 7th October with Kevin of MI as Party Chief. The survey team comprised skilled personnel from the MI, a freelance contractor and a student from Ulster University.

2.1 Survey Track Lines

The final survey track line plot is shown in figure 4. Main lines were run along east – west reciprocal headings with cross lines on north - south reciprocal headings.

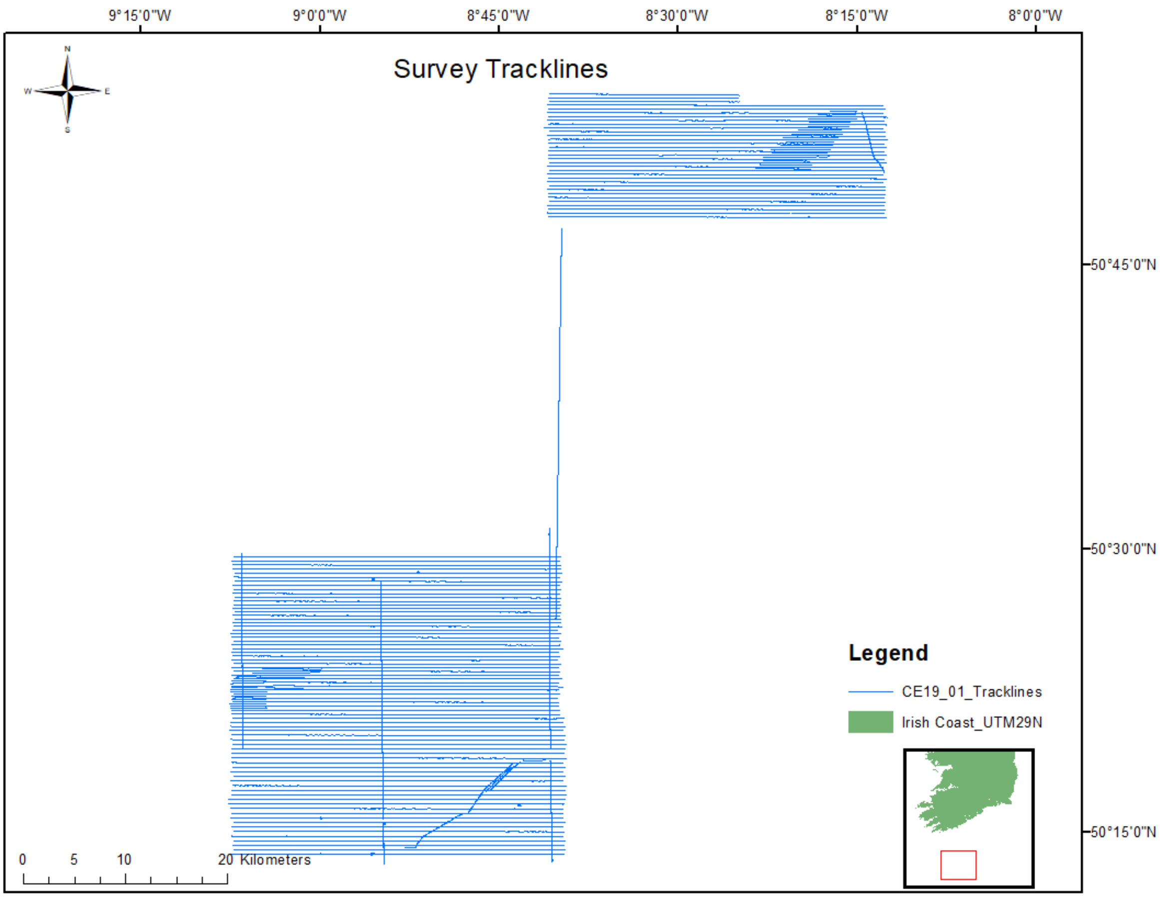


Figure 4: Survey track line plot produced in ArcGIS software.

2.2 Summary of Events

A summary of the key events is presented in table 1. Times are in Coordinated Universal Time (UTC). Daily Progress Reports (DPRs) were emailed to management and INFOMAR personnel on a daily basis.

Date and time	Activity	Comments
21/09/19 07:00	Mobilised Cork	
21/09/19 21:00	Departed Cork	Transit to Survey Area
22/09/19 07:46	Commenced Survey Operations	
24/09/19 02:44	Weather Standby	
25/09/19 17:05	Resumed Survey	
02/10/19 23:06	Weather Standby	Transit to Cork
04/10/19 18:00	Departed Cork	
05/10/19 04:48	Resumed Survey	
07/10/19 19:46	Finish Survey Acquisition	Transit to Cork
08/10/19 09:00	Alongside Cork	
08/10/19 23:59	Demobilisation completed	

Table 1: Summary of survey events.

2.3 Survey Personnel

Survey personnel are listed in table 2.

Name	Affiliation	Role
Kevin Sheehan	MI	Party Chief / Surveyor
Oisin McManus	MI	Surveyor
Fabio Sacchetti	MI	Surveyor
Slava Sobolev	Freelance	Data Processor
Jan Majcher	Ulster University	Trainee Surveyor

Table 2: Survey personnel details.

2.4 Health, Safety and Environment (HSE)

All personnel joining the vessel were given a safety induction tour which was recorded by the Second Mate. Medical and Personal Sea Survival certifications for all personnel were checked for validity prior to departure. A muster drill was held within 24 hours of departure from port. Magnetometer, grab and sound velocity profiler deployments were performed by vessel crew and without incident, with personnel wearing correct Personal Protective Equipment (PPE). There were no near misses or safety incidents to report.

2.5 Marine Mammal Observations

National Parks and Wildlife Service (NPWS) published a *Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters* in 2007. An updated document titled “Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters” was published in January 2014. Full details of both documents are published on the NPWS website. The code and guidance are applicable to all seismic, MBES and sidescan sonar surveys in bays, inlets or estuaries and within 1500 m of the entrance of enclosed bays/inlets/estuaries. All CE19_01 operations were outside of the areas covered under the above guidelines. Common Dolphins were observed during the course of the survey.

2.6 General Survey Information

A summary of principal survey statistics is contained in figure 5. The vessel was operational 65% of the time with less than 21% weather standby experienced. Survey operations were at reduced speed at times due to strong winds and rough seas but this is not accounted for in the statistics. A total of 3793 line Km and 1358 Km^2 were covered.

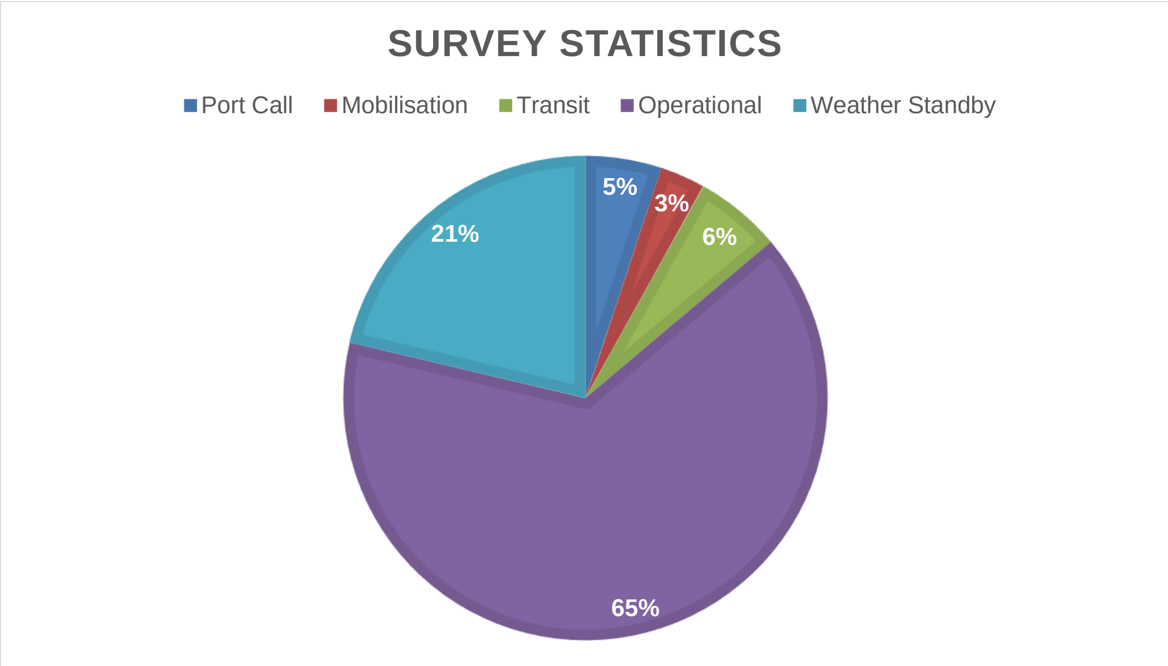


Figure 5: Survey statistics pie chart CE19_01.

2.7 Wreck and Shoal Investigations

United Kingdom Hydrographic Office (UKHO) guidelines were implemented for wreck investigations. Three survey lines along the wreck's primary axis with high overlap and one line across its secondary axis (ensuring full wreck coverage along both axes) were acquired. The water column logging functionality in SIS was used throughout the investigation. Beam angles, survey speed, operational frequency and pulse length were configured for maximum resolution.

Uncharted shoals are surveyed in a similar manner where conditions allow. Wrecks and shoals are reported to the UKHO using the standard UKHO "H-Forms". No shoals were discovered or mapped. Six wrecks were mapped in detail and wreck reports produced and distributed to the Underwater Archaeology Unit and UKHO. Table 3 contains wreck metadata information.

Descriptor	Metadata
Shoals	0
Wrecks	6

Table 3: Hydrographic investigations completed.

3 Survey Vessel Offsets, Equipment and Data Acquisition

The RV *Celtic Explorer* (figure 6) is a multipurpose research vessel owned by MI and managed by P&O Maritime. The vessel has wet, dry and chemical laboratories, which are permanently fitted with standard scientific equipment and can accommodate 35 people with a maximum endurance of 45 days. It has three high resolution MBES systems, a Singlebeam Echo Sounder (SBES), fisheries echo sounder, chirp source SBP and C-NAV Differential Global Navigation Satellite Systems (DGNSS). All necessary geophysical and DGPS positioning equipment were pre-installed, calibrated and tested prior to commencement of survey activities.

Figure 6: The RV *Celtic Explorer*.

Detailed vessel information is contained in table 4.

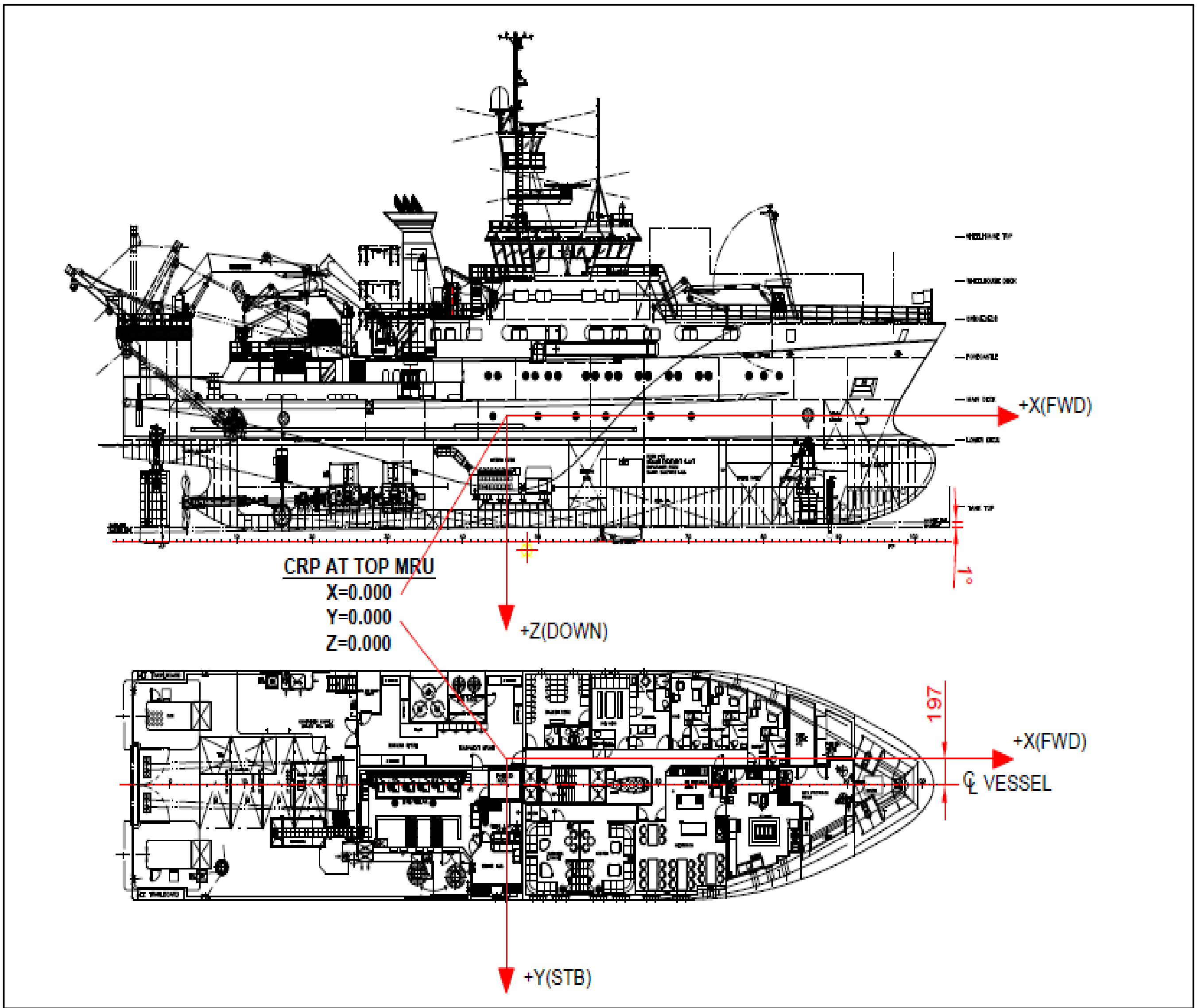
Length	65.5 m
Beam	15 m
Draught	6.0 m
Engine	1 x 6L20, 2 x 9L20
Power Output	1 x 1080 kWa, 2 x 1680 kWa
Speed	10 knots
Fuel	4600 Lt per day MGO

Generator	1 x 1080 kWa, 2 x 1680 kWa
Max Scientists and Crew	35
Passenger Licence	P5

Table 4: RV *Celtic Explorer* vessel information.

3.1 Vessel Offsets

Bluepix AS performed a vessel offset survey between 10th and 15th January 2015 while the vessel was in dry dock in Falmouth, UK. An EM302 deep water MBES and an IxBlue ECHOES3500 Chrip system were installed on the vessels hull during this dry dock. Vessel offsets are presented in table 5 below.



Item	Y (+Stb)	X (+Fwd)	Z (+Down)	Description
MRU5+	0,000	0,000	0,000	Position Centre Top
EM302 TX	0,199	20,022	7,056	Position Centre Face
EM302 RX	0,202	17,574	7,106	Position Centre Face
EM 2040 TX	0,416	11,204	7,205	Position Centre Face
EM 2040 RX	0,111	11,098	7,192	Position Centre Face
EM 1002	0,195	13,846	7,964	Position Centre U/S
Seapath aft	0,235	1,506	-25,006	Geometric Centre
Seapath Fore	0,205	3,980	-24,966	Geometric Centre
C-Nav	-0,211	2,838	-24,925	Geometric Centre U/S Antenna
IXSEA ECHOS SBP	0,194	16,317	7,130	Centre Face
ES 120	-0,073	12,289	7,161	Centre Face
ES 38	0,199	12,581	7,160	Centre Face
ES 200	0,474	12,290	7,167	Centre Face
ES 18	0,203	11,901	7,171	Centre Face
USBL 1 and 2	0,212	9,988	7,239	Flush U/S Drop keel
Draftsensor Fore Stb	3,484	23,316	4,181	Centre Flush Hull
Draftsensor Fore Port	-3,067	23,314	4,185	Centre Flush Hull
Draftsensor Port Midship	-7,053	-5,133	4,436	Centre Flush Hull
Draftsensor Stb Midship	7,608	-4,067	4,400	Centre Flush Hull
Draftsensor Aft Stb	2,064	-14,217	6,240	Centre Flush Hull
Stb Point for draft measurement	7,719	-4,582	-2,179	Railing Stb side
Stb Point for draft measurement	7,147	11,245	-4,985	Welded mark
Port Point for draft measurement	-7,474	-1,969	-4,945	Railing Port side

Item	Pitch	Roll	Yaw
MRU 5+	0.73	-1.11	-0.36
EM2040 TX	1.25	-0.38	-0.23
EM2040 RX	0.55	0.16	-0.12
EM302 TX	1.03	0.42	-0.05
EM302 RX	1.68	0.06	0.04
Seapath	N/A	N/A	-0.70
EM1002	0.86	0.01	-0.65

Positive Yaw is clockwise. Positive Roll is starboard down. Positive Pitch is fore up.

Table 5: Vessel offsets and installation angles.

3.2 Survey Equipment

Table 6 contains information on the survey equipment both permanently installed and available for mobilisation onboard the RV *Celtic Explorer*.

Data System	Make/Model	Comment
Multibeam Echo-Sounder	Kongsberg EM2040	200, 300 & 400 kHz
Multibeam Echo-Sounder	Kongsberg EM302	26.5 to 33.5 kHz
Fisheries Echo-Sounder	Kongsberg EK60	18, 38, 120 & 200 kHz
Chirp Sub-Bottom-Profiler	iXblue Echoes 3500 T7	3.5 – 9 kHz

Positioning	C-Nav DGNSS	Seapath330+ as secondary
USBL	iXblue-Gaps	Sonardyne Ranger 2 as secondary
Sound Velocity Profilers	Valeport SVX2 & SVP Mini	SV & Conductivity
Moving Velocity Profilers	AML MVP-200	CTD & SVP sensor
Realtime Sound Velocity	Valeport & AML	
Magnetometers	SEASPY	Overhauser Effect

Table 6: RV *Celtic Explorer* available survey equipment.

3.2.1 Technical Issues

EM2040 Attitude Delay

The on-board data processor noticed an artefact in the data. Figure 7 shows a data example with no time delay applied.

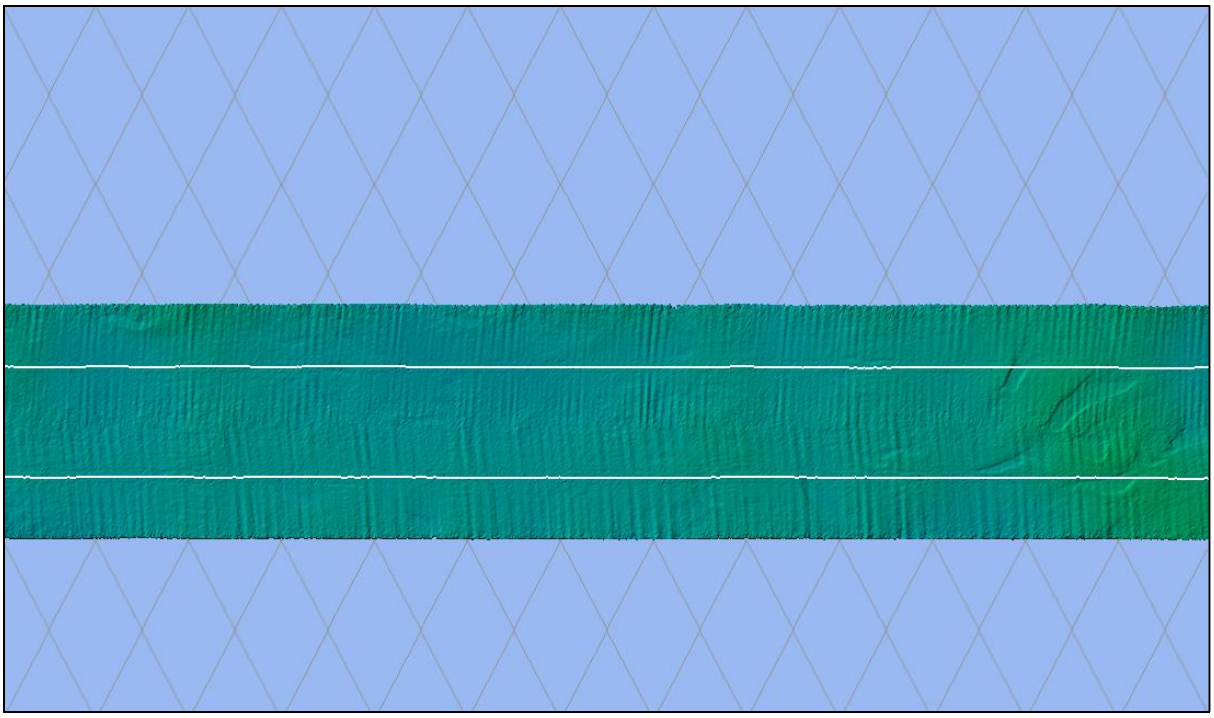


Figure 7: Data example with no time delay.

A series of QC steps were taken and it was determined in Qimera that adding a 35 ms time delay in SIS was the best way to mitigate the data artefact. Figure 8 shows the same data with a 35 ms time delay applied in post processing.

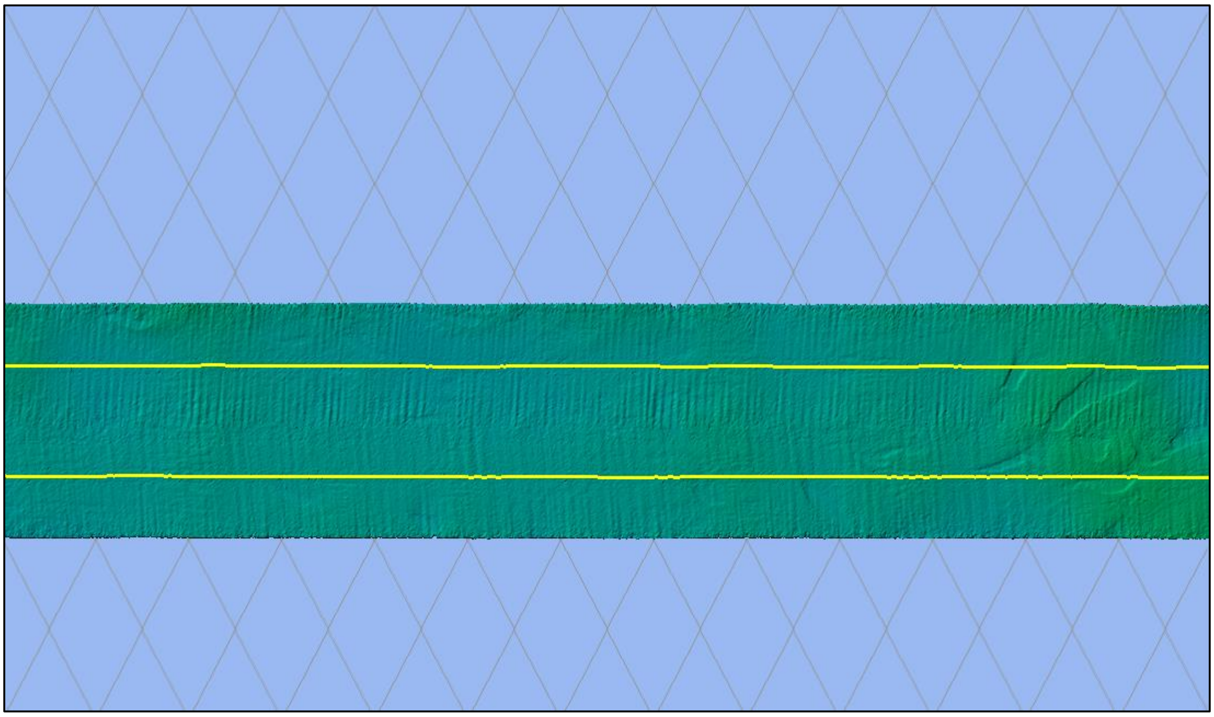


Figure 8: Data example with 35 ms time delay.

MVP Configuration Issues

The depth feed was not detected. We tried to setup the UDP output using the DATADISTRIB software in the EM2040 as previously configured but that wouldn't work. Eventually we setup the UDP output in the EK60 software (Figure 9). A DBS output string was configured. UDP settings have to match on EK60 and MVP configurations in order to work. The configuration field on the top right corner of the configuration window required setting up. The correct field (field 3) for depth was selected.

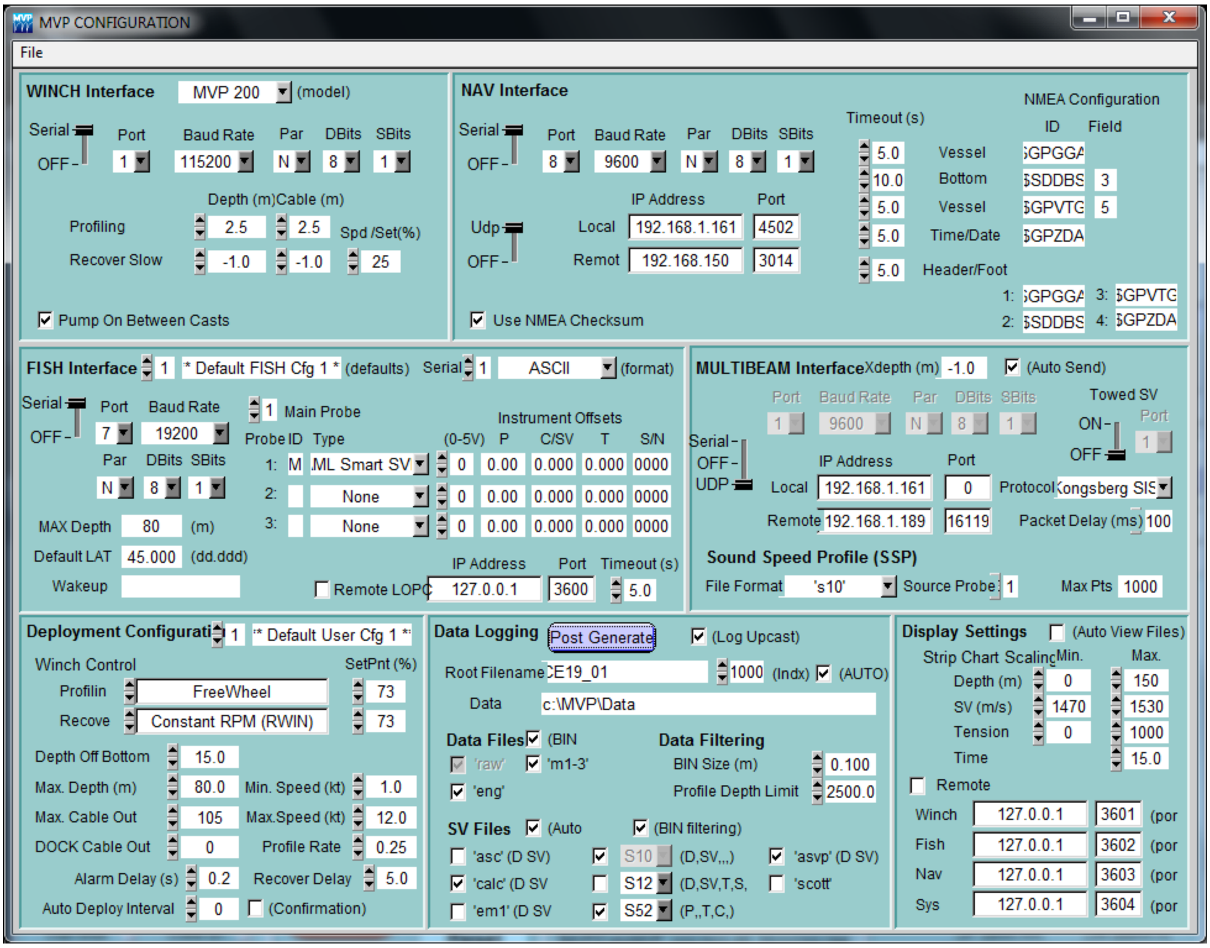
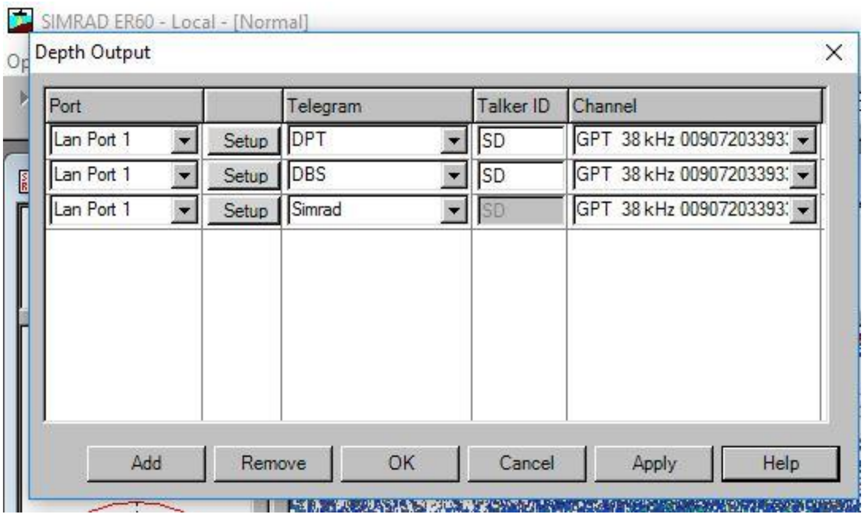


Figure 9: MVP configuration settings.

The EK60 settings are shown in figure 10.



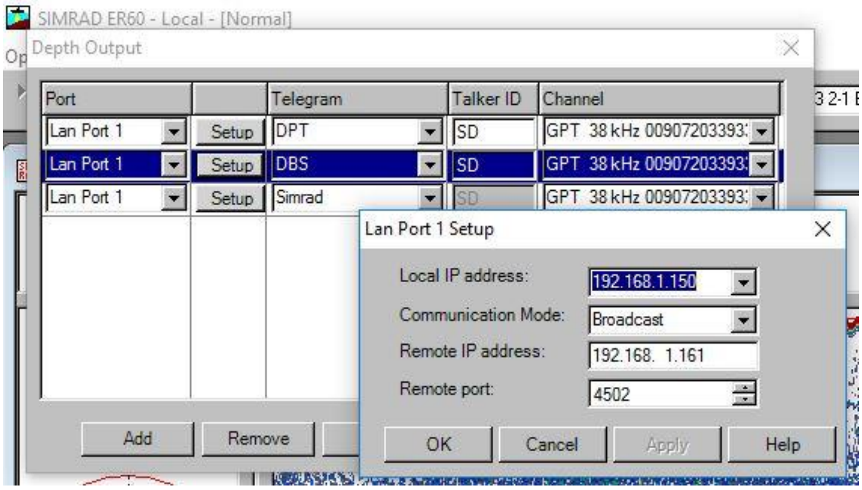
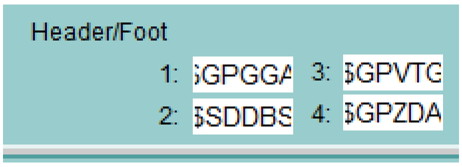


Figure 10: EK60 settings for MVP configuration.

The vessel speed feed was absent as the CNAV string output was missing the GPVTG string. Once activated, we had to specify where the "speed data" is in the string, i.e. field 5. The time in the asvp file was incorrect. While time appeared decoded from the ZDA string, when saved in the ASVP header it was 1-hour out. Empty header fields in the MVP configuration were populated with the correct decoded string.



MVP Cable Short

Data dropouts (figure 11) appeared on the MVP software on 29th September and the system became unusable. The towfish was recovered on deck. Several days of troubleshooting ensued and the tow cable was cut back sufficiently beyond a short to make the system operable again on 5th October.

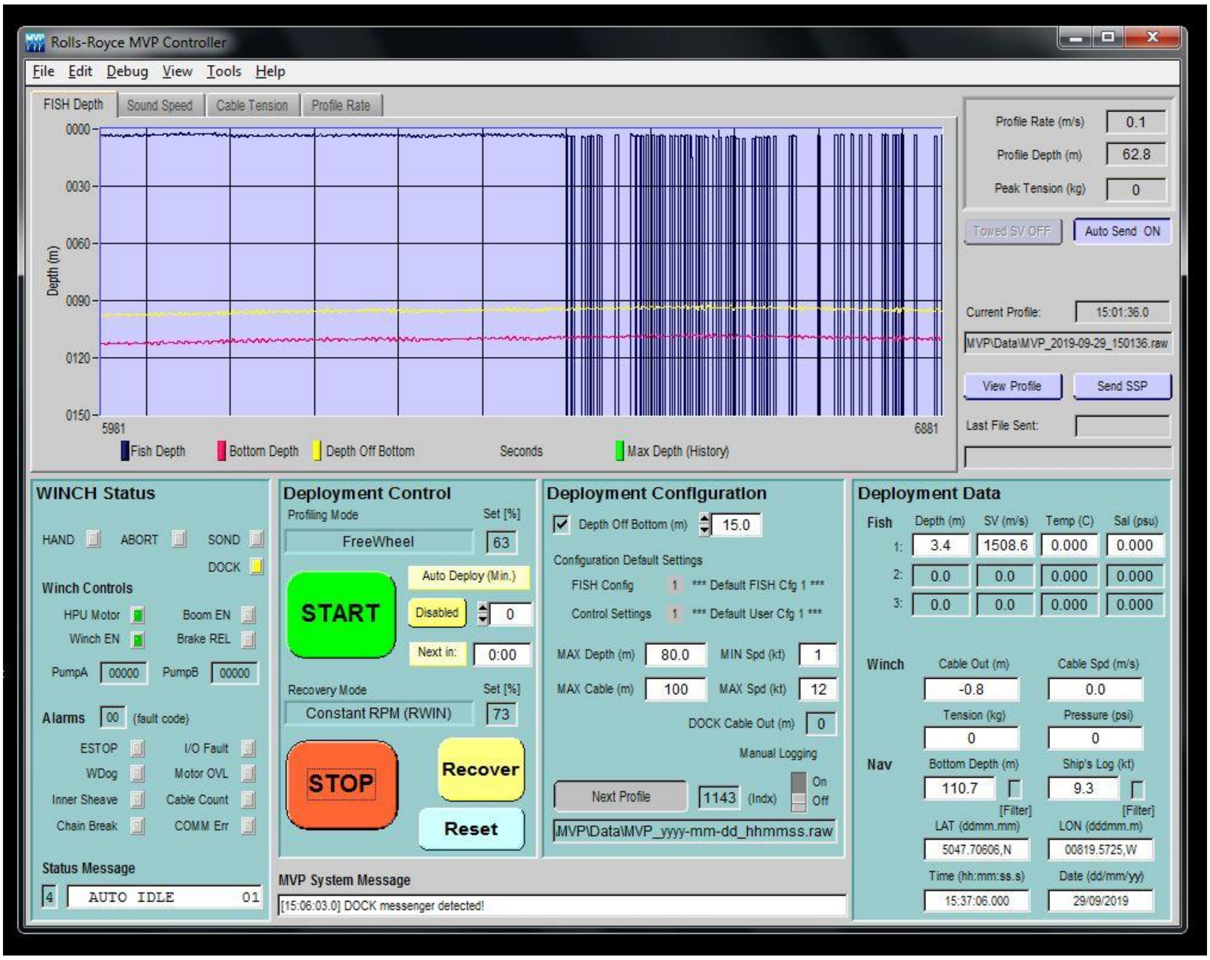


Figure 11: MVP controller software showing data dropouts.

Chirp SBP Heave Data Issue

An analysis of SBP data showed that for some survey lines the heave correction in Delph software does not work or only partially works. Further investigation revealed that all lines displaying this heave issue were non mainlines, i.e. wreck investigation or infill lines. More testing is required to understand the source of this issue. Figure 12 shows poorly heave corrected data on line 214.

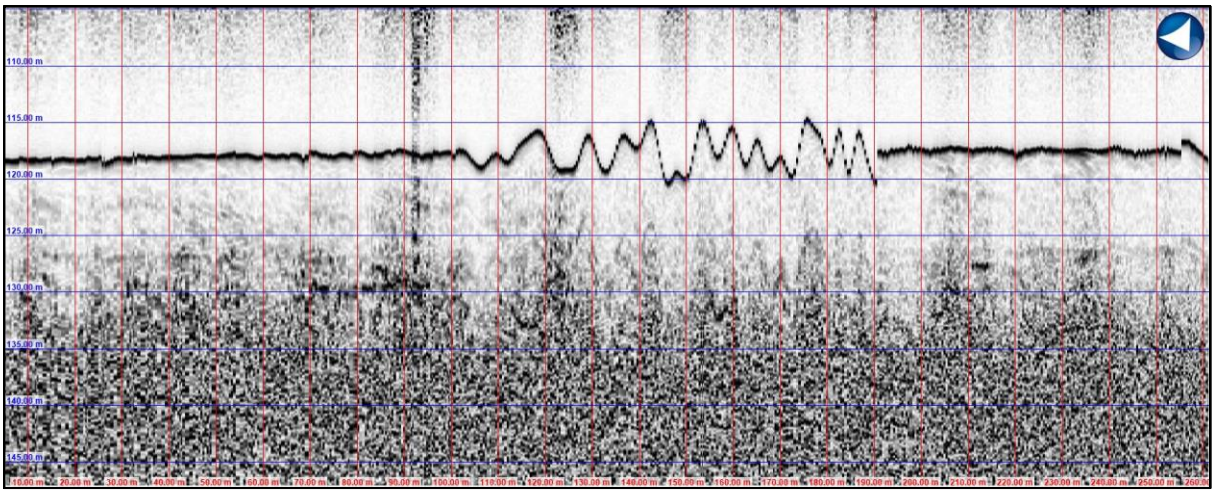


Figure 12: SBP heave correction issue on line 214.

3.3 Data Acquisition

3.3.1 Geodetic Parameters

Table 7 contains the geodetic parameters used for the survey.

Local Datum Geodetic Parameters	
Datum	ITRF2014
Spheroid	World Geodetic System 1984 (WGS-84)
Semi-Major Axis (a)	6378137.000 m
Semi-Minor Axis (b)	6356752.314 m
First Eccentricity Squared (e^2)	0.0066943800
Inverse Flattening (1/f)	298.257223563
Projection Parameters	
Grid Projection	Universal Transverse Mercator
Central Meridian Zone 29 (CM)	009º West
Origin Latitude (False Lat.)	00.0°
Hemisphere	North
False Easting (FE)	500000.0 m
False Northing (FN)	0.0 m
Scale Factor on CM	0.999600
Units	Metres

Table 7: Geodetic parameters.

3.3.2 Survey Datum, GNSS Tides and VORF Model

Table 7, above details the vertical and horizontal datum applied during operations. Global Navigation Satellite Systems (GNSS) tides do not require accounting for vessel draft or vessel squat values, as recorded depths are related directly to the WGS84 Ellipsoid. These values were reduced to Lowest Astronomical Tide (LAT) using *GNSS* tidal measurements and by then applying the VORF (Vertical Offshore Reference Frame) model (LAT/WGS84 separation) as illustrated in figure 13 below.

A validation of the LAT vertical datum output from the VORF model was undertaken between 2013 and 2016, using tide gauges and harmonic analysis, at key locations around the Irish coast.

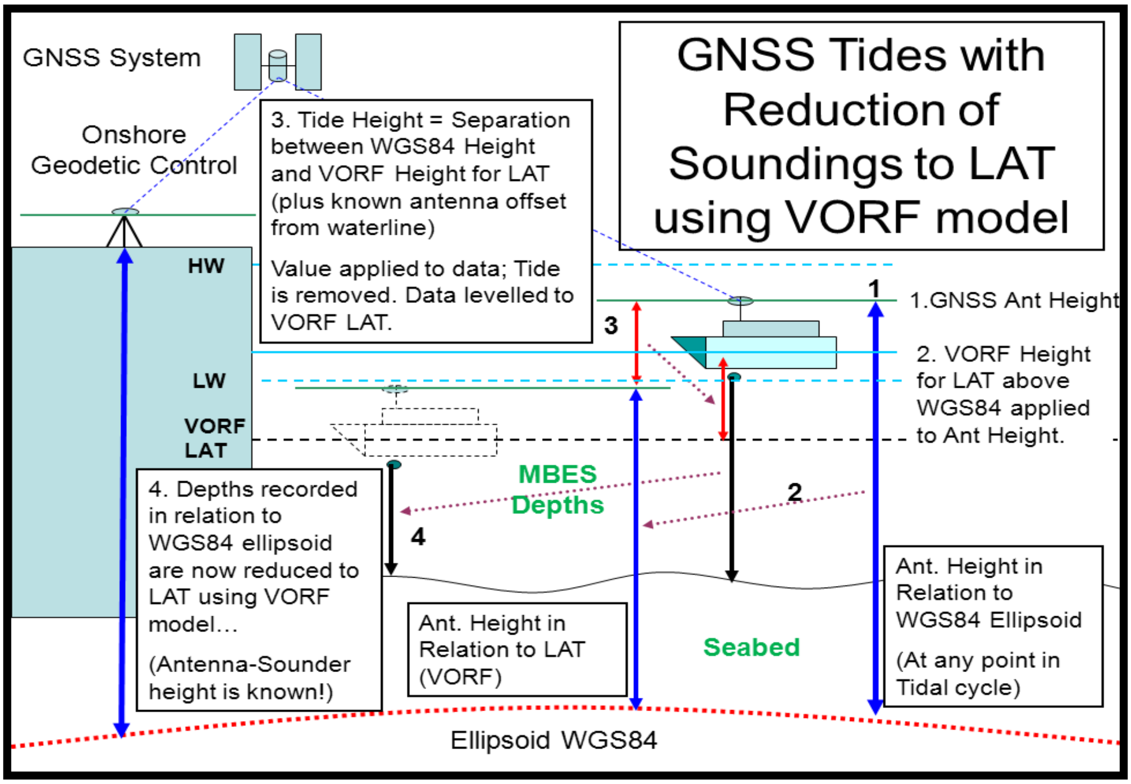


Figure 13: GNSS tides to LAT using VORF model.

3.3.3 Vessel Draft

Distances from known draft measuring points on the vessels port and starboard sides to the water line were measured by tape once ballasting was completed. Known vertical distances at port and starboard sides between these draft measuring points and the MRU (Common Reference Point for EM2040) were used along with the tape measured vertical distances to calculate draft values for the echosounders. Port and starboard sides were averaged to get one value for each echosounder. Table 8 lists the tape measured draft figures along with the known vertical distances.

Measurement	Port Side	Starboard Side
Tape Measurement at Draft Mark (from mark to water) 21/09/2019	-6.85 (E)	-3.95 (D)
Vertical distance between Starboard Side draft mark and MRU		-2.179 (A)
Vertical distance between Port Side draft mark and MRU	-4.945 (B)	

Table 8: Draft measured and known vales.

Draft value for EM2040 = ((D - A) + (E - B))/2

Draft value for EM2040 = ((-3.95 - -2.179) + (-6.85 - -4.945))/2 = **-1.838**

This draft value was entered in the respective software for all echosounders.

The EM2040 transducers are situated on the vessel dropkeel. The dropkeel can be placed in a range of positions including flush with the hull or fully deployed. The vertical measurement by tape is 7.75 m when the dropkeel is in the flush position. The vertical measurement by tape for this survey when the dropkeel was in the fully deployed position was 10.40 m. Difference between flush position and fully deployed position is 10.40 – 7.75 = 2.65 m. This figure was entered in SIS as an additional z offset. The vertical measurement when in the fully deployed position may be subject to minor variation so should be measured for each deployment.

3.3.4 Multibeam Systems

The RV *Celtic Explorer* is equipped with three MBES systems; EM2040, EM1002 and EM302, capable of high precision seabed mapping from shallow water to full ocean depths. The EM2040 MBES is designed for high resolution mapping down to approximately 400 metres water depth. The EM1002 is now an obsolete system in terms of bathymetric data but its main benefit is the ability to acquire excellent backscatter data on the shelf and slope down to depths of 900 metres. A hull mounted EM302 provides additional multispectral data and is designed to perform seabed mapping with high resolution and accuracy to a maximum depth of more than 7000 metres.

The EM2040 positioned on the drop keel is the primary system for high resolution seafloor mapping on the continental shelf. First bottom returns from the MBES produce highly accurate bathymetric data. Backscatter acquired by MBES sonars contains important information about the seafloor and its physical properties. This information provides valuable data to aid in seafloor classification and important auxiliary information for a bathymetric survey. The EM2040 can also collect water column data for oceanographic investigations and for detection of objects above the seafloor.

The EM2040 installation consists of single RX transducer and a single TX transducer, 0.7º x 0.7º. The system operates at frequencies of 200, 300 or 400 kHz with 400 soundings per ping and allows coverage of up to 5 times water depth on a flat bottom. It has a maximum ping rate of 50 Hz. The 200 kHz frequency was used for general mapping and 300 kHz for wreck investigations. Positioning was provided by C-Nav 3050 DGNSS and these data were integrated with inertial measurement units by a Seatex Motion Reference Unit (MRU) model Seapath 330+ to give real time heading, heave, pitch and roll, position and velocity of the MBES system.

The EM302 transducers are modular linear arrays in a Mills cross configuration with separate units for transmit and receive. The transmitter array is 1º resolution and the receive array 2º resolution. It has dual swath capability meaning that 2 swaths are generated per ping cycle, with up to 864 soundings. The system has an operating frequency of 30 kHz. It can also acquire water-column data.

The EM1002 is mounted on a retractable pole and consists of a single semi-circular transducer. The transceiver unit contains both transmit and receive electronics. It has a 2X2º beam width, with 111 beams per ping, operating at a central frequency of 95 kHz.

MBES data was recorded in .all and .wcd formats using Kongsberg's SIS software. Raw.all files from the MBES's were continuously backed up on the vessel server. Water column data was acquired throughout with EM2040 and EM302 and written straight to portable disk drives as file sizes are very large. The EM1002 is unable to record water column data. Table 9 contains MBES metadata.

Descriptor	Metadata
Survey lines	All
Date Created	22-09-2019 to 07-10-2019
EM2040 Data Files	240
EM302 Data Files	204
EM1002 Data Files	47
EM2040 Dataset Size	49.5 GB
EM2040 Watercolumn Size	Stored on separate disk
EM302 Dataset Size	78.8 GB
EM302 Watercolumn Size	Stored on separate disk

EM1002 Dataset Size	2.04 GB
EM2040 File Formats	.all, .wcd
EM302 File Formats	.all, .wcd
EM1002 File Formats	.all

Table 9: MBES metadata.

3.3.5 Singlebeam Systems

An EK60 fisheries echosounder mounted on the drop keel provided data for investigation of the thermocline. The EK60 is a multiple frequency system with 18, 38, 120 and 200 kHz capability. The 200 kHz frequency was switched off throughout as it interfered with the EM2040.

EK60 data was recorded in .raw format using Kongsberg's acquisition software. Data was backed up to the vessel server at the end of each line. Table 10 contains EK60 metadata.

Descriptor	Metadata
Survey lines	
Data Files	996
Date Created	22-09-2019 to 07-10-2019
Dataset Size	28.1 GB
File Formats	.bot, .idx, .raw

Table 10: SBES metadata.

3.3.6 Echoes Chirp Sub-Bottom Profiler

The vessel is equipped with a hull-mounted SBP situated just behind the EM302. Echoes 3500 T7 is a low frequency chirp SBP, based on seven transducers. The transmitted pulse is frequency and amplitude-modulated. The frequency modulation ranges from 1.7 kHz to 5.5 kHz, centred on 3.5 kHz, with a 100ms Chirp. The selected bandwidth allows for good penetration and high resolution. Acquisition is controlled in Delph acquisition software.

Raw data was recorded in XTF format for each survey line. Positioning data was provided from C-Nav DNSS and MRU data was fed directly from the Seapath 330+. The realtime attitude data can be seen in the Delph acquisition software but it is not applied to the seismic data in realtime. One set of acquisition parameters, based on 100 m water depth was utilised throughout the survey. Table 11 contains SBP metadata.

Descriptor	Metadata
Survey lines	All
Data Files	768
Date Created	22-09-2019 to 07-10-2019
Dataset Size	76.3 GB
File Formats	.XTF, .GEO, .PRM & .idx

Table 11: SBP metadata.

3.3.7 Magnetometer

A Marine Magnetics Corporation SeaSPY towed Overhauser Magnetometer was used to acquire magnetic field data. The system comprises a towfish, tow cable, deck lead and transceiver interfaced to a standard Windows based PC. Acquisition parameters and QC were controlled via BOB software.

The magnetometer was towed 200 m behind the vessel at a depth of less than 5 m beneath sea surface. Magnetometer and GPS data from the towfish were input to the control PC via separate serial ports and synchronised. Initial QC was performed via real-time graphing of the magnetic field trace and by monitoring real-time GPS data. Magnetometer data were recorded in a database using BOB software and output in both proprietary BOB format as .mms file format. Metadata is contained in table 12.

Descriptor	**Metadata**
Survey lines	NA
Data Files	1
Date Created	22-09-2019 to 07-10-2019
Dataset Size	634 MB
File Formats	.mms

Table 12: Magnetometer metadata.

3.3.8 DGPS Systems

C-Nav DGNSS provided the primary navigation. The C-Nav 3050 is a dynamic DGNSS Precise Point Positioning (PPP) system providing accuracy of <0.1 metre horizontally and 0.2 metre vertically. It provides 66 channel tracking, including multi-constellation support for GPS, GLONASS and Galileo. C-Nav provided the primary navigation feed for all survey equipment. C-Nav also provided a reliable GPS tide correction.

The C-Nav DGNSS receiver was connected to the server VDU for QC purposes. C-Nav has a range of QC output displays that were monitored in real-time including number of satellites in use, satellite attitude and angles, vertical accuracy, vessel speed, heading and precise position. GPS signal was always very good and the system never lost the Real Time Gypsy (RTG) solution. A hard disk connected to the C-Nav receiver provided real-time data storage.

Seapath 330+ provided the secondary navigation. Seapath and C-Nav data were continuously checked in Quality Integrated Navigation System (QINSy) software to ensure data integrity and comparison between the primary and secondary navigation systems remained within tolerance. Navigation data were recorded in .cnav3050 format using C-Nav software. One file per day was created. Metadata is contained in table 13.

Descriptor	Metadata
Survey lines	NA
Data Files	17
Date Created	21-09-2019 to 07-10-2019
Dataset Size	5.02GB
File Formats	.cnav3050

Table 13: C-Nav navigation metadata.

3.3.9 Online Navigation

QINSy software was used for navigation acquisition and QC. QINSy performs visual and QA data-feeds from the key acquisition systems. A project template database was created containing all survey configuration parameters relevant to the project. The project template contains the datum, projections, vessel shape, administrative information, as well as vessel offsets and I/O parameters. QINSy uses a sophisticated timing routine based on the Pulse Per Second (PPS) option from the GNSS receiver. All incoming and outgoing data is accurately stamped with a UTC time label.

Survey line and MVP positioning data were recorded in QINSy software in .db and .txt format. The QINSy navigation .txt file was input to the Multilog database to provide a record of navigation information for the purpose of recording survey metadata for each survey system. QINSy metadata is provided in table 14.

Descriptor	Metadata
Survey lines	All
Data Files	617
Date Created	22-09-2019 to 07-10-2019
Dataset Size	19.6 GB
File Formats	.db & .txt

Table 14: QINSy Navigation metadata.

3.3.10 Sound Velocity Profilers & Sensors

An AML Moving Vessel Profiler (MVP) 200 (figure 14) was the primary instrument to obtain sound velocity profile data for the echosounders. The major benefit of the MVP is that the vessel did not have to stop to acquire SVP data resulting in more frequent casts and without impacting survey productivity.

Figure 14: AML Oceanographic MVP-200.

The MVP-200 was fitted with a Smart SVP sensor capable of directly acquiring sound velocity data. MVP deployment was controlled from the vessel Dry Lab using Rolls Royce MVP software. The probe was continually towed in the water at 5 metres depth off the starboard aft side and deployed to within 20 metres of the seabed during casts. Sound velocity profiles were extended in SIS and fed directly into all echosounders.

A Valeport SVP Mini instrument was used to acquire profiles for the period when the MVP was inoperable. Data were exported in asvp format from the instruments and input to SIS.

Both Valeport and AML sound velocity sensors positioned at the transducer heads provided real time sound velocity input directly to the EM2040 and EM302 respectively. Profile metadata is contained in table 15.

Descriptor	Metadata
Survey lines	NA
Data Files	264
Date Created	22-09-2019 to 07-10-2019
Dataset Size	297 KB
File Formats	.asvp

Table 15: Sound velocity metadata.

3.3.11 Multilog

A Microsoft Access database was used for logging survey metadata. Data acquisition parameters, data QC, sound velocity and daily progress report information were input and recorded. Database backups were made regularly using its inbuilt functionality.

4 Online QC, Data Processing, Results and Interpretation

The hydrographic survey was performed to International Hydrographic Organization (IHO) survey standard Order 1a for water depths less than 100 metres and Order 2 for areas exceeding 100 metres depth. This represents the minimum standard for position, depth accuracy and feature detection achieved during data acquisition and processing. Order 1a and Order 2 requirements are presented in table 16.

	Order 1a (S-44)	**Order 2 (S-44)**
Description of Areas	Shallower than 100m, features of concern to shipping.	Areas generally deeper than 100 m where a general description of the sea floor is considered adequate.
Max THU allowable (95%C)	Total Horizontal Uncertainty (THU) 5m+5% of depth	Total Horizontal Uncertainty (THU) 20 m+10% of depth
Max TVU allowable (95%C)	Total Vertical Uncertainty (TVU) a = 0.5 metre b = 0.013 $\pm\sqrt{a^2 + (bxd)^2}$	Total Vertical Uncertainty (TVU) a = 1.0 metre b = 0.023 $\pm\sqrt{a^2 + (bxd)^2}$
Full Seafloor Search	Required	Not Required
Feature Detection	Cubic Features > 2m (Depths < 40m) 10% depth > 40m	Not Applicable
Recommended Max line spacing	Full Seafloor search	4 x average depth

Table 16: IHO standards for hydrographic surveys

4.1 MBES Online Quality Control

4.1.1 Acquisition Parameters

Most of the important acquisition parameters are set in the Runtime Parameters module of SIS. Figure 15 shows the Sounder Main tab in Runtime Parameters for the EM2040. Max angle and max coverage parameters were adjusted to take account of depth, sea state and seafloor character. Pulse type was set to auto throughout, which based on the angle and coverage settings, defaulted to FM pulse. The 200 kHz frequency was used throughout apart from wrecks surveys. Coverage, max angle and vessel speed were adjusted for wreck surveys.

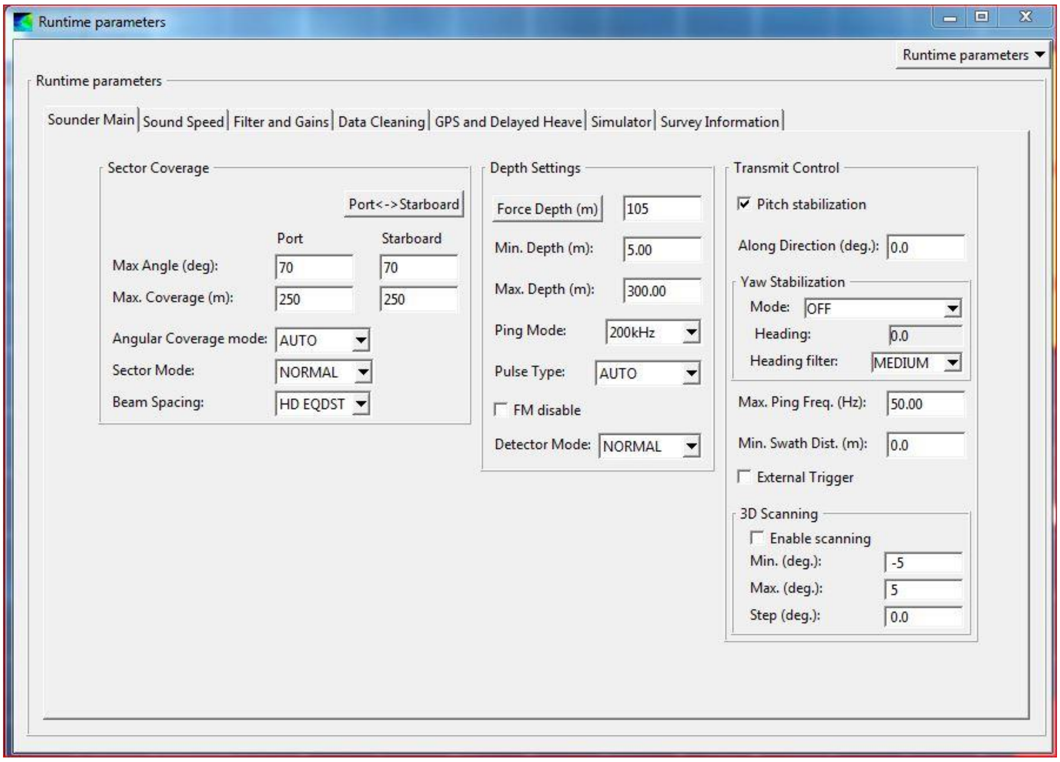


Figure 15: EM2040 runtime parameters window in SIS.

4.1.2 Crossline versus Mainline Statistics

Crossline data were acquired for QC of depth soundings. A total of 8 crosslines were acquired for statistical analysis in Caris Hips. EM2040 crossline data were compared with mainline data and all crossline data indicated that the soundings exceeded the 95% certainty required for Order 1a specification. Crossline statistics are presented in table 17.

Line	Beam No.	Count	Max (+)	Min (-)	Mean	Std Dev	Special Order (%)	Order 1a (%)
0091	1-400	1,894,004	11.185	10.928	-0.063	0.237	99.851	99.963
0131	1-400	1,283,676	0.787	2.748	-0.163	0.189	99.957	99.998
0190	1-400	4,343,461	1.023	1.073	0.008	0.210	99.985	100
0191	1-400	4,128,033	1.142	0.985	0.001	0.179	99.999	100
0234	1-400	1,869,544	0.920	1.142	-0.096	0.182	99.998	100
0244	1-400	744,214	2.809	4.459	-0.058	0.190	99.814	99.967
0249	1-400	4,824,875	1.120	1.213	-0.067	0.202	99.996	100
7000	1-400	611,720	1.275	1.388	-0.072	0.204	99.962	100

Table 17: Multibeam crossline statistics.

4.1.3 Feature Detection

The minimum standard for feature detection for an Order 1a survey are cubic features > 2 metres in depths up to 40 metres and cubic features >10% of depth beyond 40 metres. This means that in 40 metres water depth 9 soundings are required in a 2m^2 bin and in 100 metres water depth 9 soundings are required in a 10m^2 bin. Feature detection is not an IHO standard requirement for depths exceeding 100 metres, *where a general description of the sea floor is considered adequate*. Approximately 80% of the area is deeper than 100 metres, the exception being the top of some of the ridges. Order 1A feature detection criteria are required for the 20% of the area shallower than 100 metres.

Feature detection statistics were run for both the north and south areas respectively. The entire dataset was analysed at Order 1a specification because it wasn't practical to sub-divide into areas shallower and deeper than 100 metres. The minimum depth in the north area of 74 metres was selected as the water depth to check feature detection statistics. Data was binned at 10% of minimum water depth or 7.4m^2 as per IHO order 1a requirement. Figure 16 shows the feature detection statistics. The mean number of soundings per bin is 49, exceeding the 9 required for feature detection.

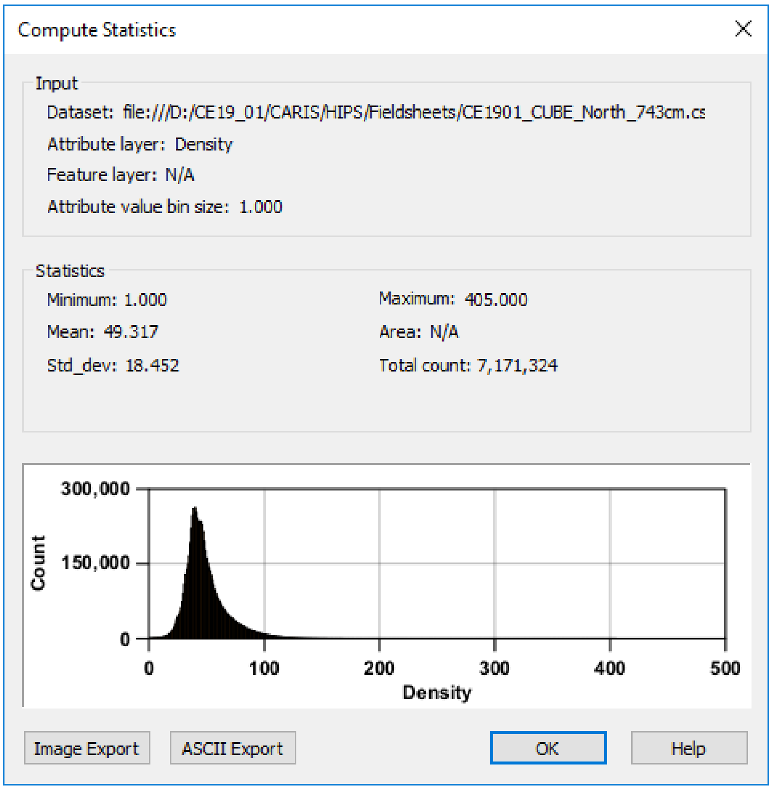


Figure 16: Feature detection statistics north area.

A full seafloor search was achieved in areas shallower than 100 metres in accordance with IHO Order 1a requirement. Figure 17 shows the corresponding sounding density plot for the north area with green indicating where at least 9 pings per bin were achieved and red where this wasn't achieved. Red colours are sporadic on this plot and are almost exclusively found in areas deeper than 100 metres, where feature detection is not applicable.

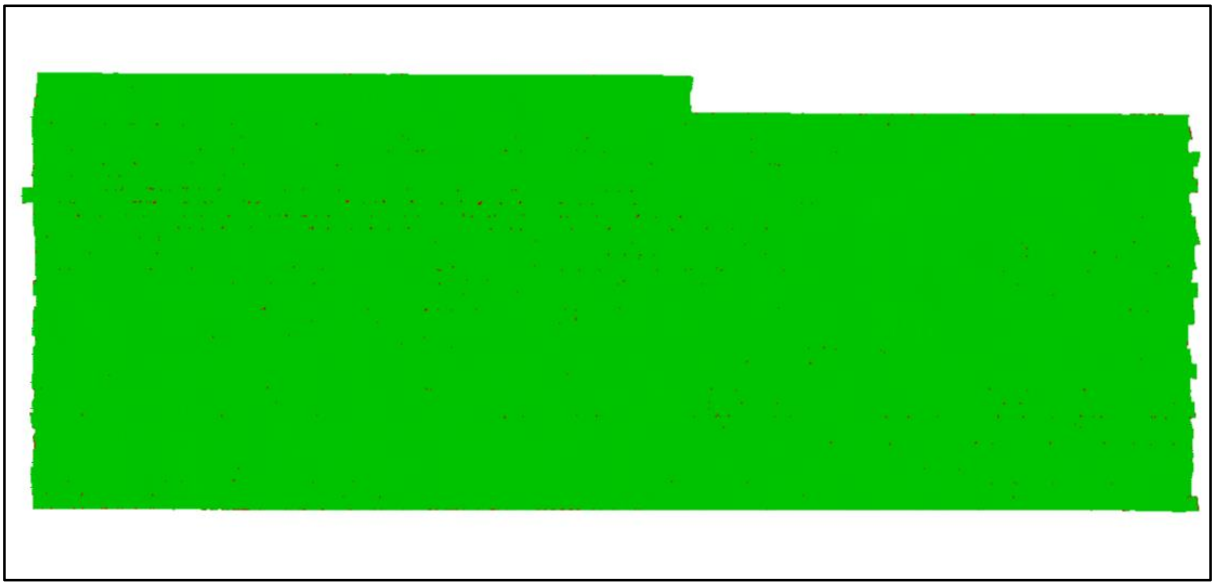


Figure 17: Sounding density QC plot north area.

The minimum depth of 86 metres was selected as the water depth to check feature detection statistics in the south area. Data was binned at 10% of minimum water depth or 8.6m^2 as per IHO order 1a requirement. Figure 18 shows the feature detection statistics. The mean number of soundings per bin is 46, exceeding the 9 required for feature detection.

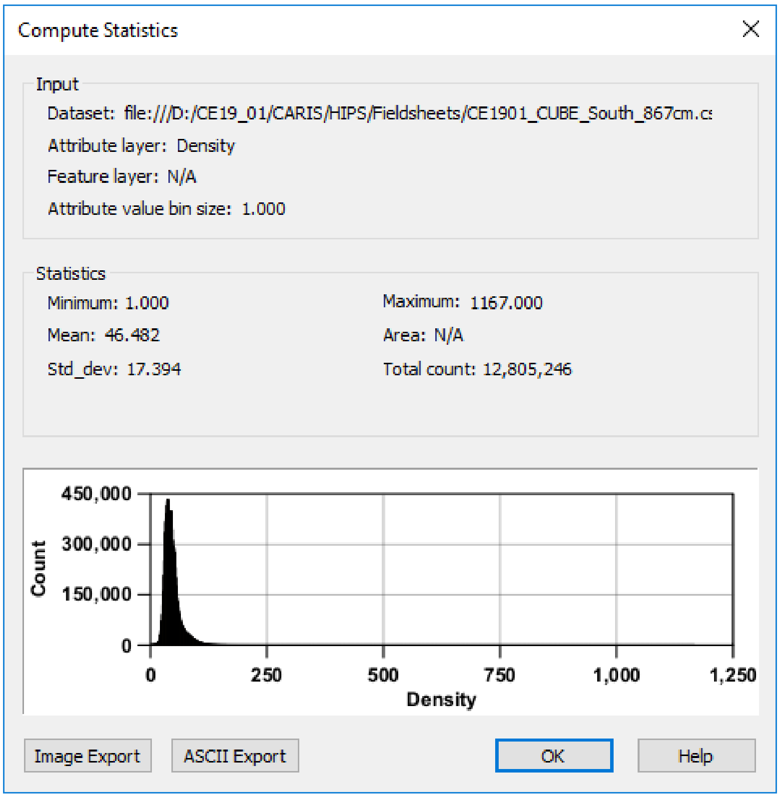


Figure 18: Feature detection statistics south area.

A full seafloor search was achieved in areas shallower than 100 metres in accordance with IHO Order 1a requirement. Figure 19 shows the corresponding sounding density plot for the south area with green indicating where at least 9 pings per bin were achieved and red where this wasn't achieved. Almost the entire plot is green, illustrating that the feature detection criteria were achieved throughout.

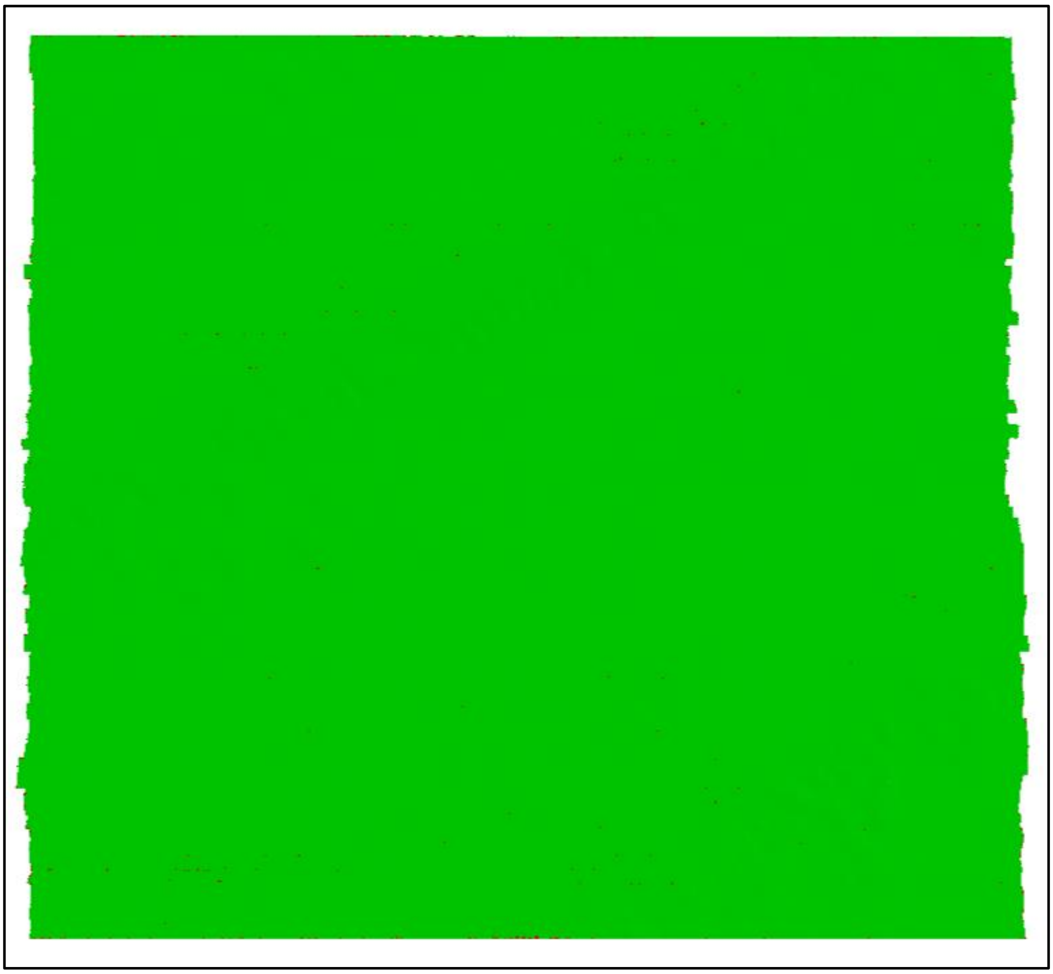


Figure 19: Sounding density QC plot south area.

4.1.4 Error Budget and Uncertainty Model

Manufacturer values for positioning and sounding errors were factored into the vessel error budget. Vessel offsets were established through an onshore dimension control survey (see section 3.1). In addition; uncertainty levels over positions of soundings were improved through good sound velocity control while surveying. Calibration of the MBES through a standard patch test, combined with good online quality control, ensured that the vessel's error budget fell within IHO 1a specifications.

Table 18 below details Standard Deviation values applied in the calculation of the vessel's Total Propagated Uncertainty (TPU) model. TPU is an estimate of the uncertainty of any individual sounding, taking into account the uncertainty estimates of the component measurements (tide, sound speed, draft, range measurement, angle measurement, attitude, offsets etc). TPU is expressed as a separate value in horizontal and vertical planes. The uncertainty of each sensor was entered in the HIPS Vessel File (HVF) and the TPU calculated.

Heading Accuracy	0.065 deg
Heave	5 cm or 5 % Amplitude
Roll	0.01 deg
Pitch	0.01 deg
Pitch Stabilised	0.00 deg
Position Navigation	0.1 m
Timing Transducer	0.00 s
Timing Navigation	0.00 s
Timing Gyro	0.00 s
Timing Heave / Pitch / Roll	0.00 / 0.00 / 0.00 s
Sound Velocity Measured	0.001 m/s
Sound Velocity Surface	0.001 m/s
Offsets X / Y /Z	X=0.01 / Y=0.01 / Z=0.01
MRU Alignment	Gyro=0.1 / Pitch=0.1 / Roll=0.1
Vessel Speed	0.03
Vessel Loading	0.00
Vessel Draft	0.00 (Use of GPS tides)
Delta Draft	0.00

Table 18: Standard deviation values used in TPU calculation.

4.1.5 Sound Velocity Control

MVP's were acquired frequently except for the period 29th September to 5th October when the system had technical problems. SVP's were acquired during this time period. Profiles served the dual purpose of calibrating the echosounders and investigating the characteristics of the thermocline. Profiles were checked, extended and entered to the online systems as soon as possible. A subset of MVP and SVP profiles are plotted in figure 20. The main feature of the profiles is a well-established thermocline at depths of between 25 and 55 m.

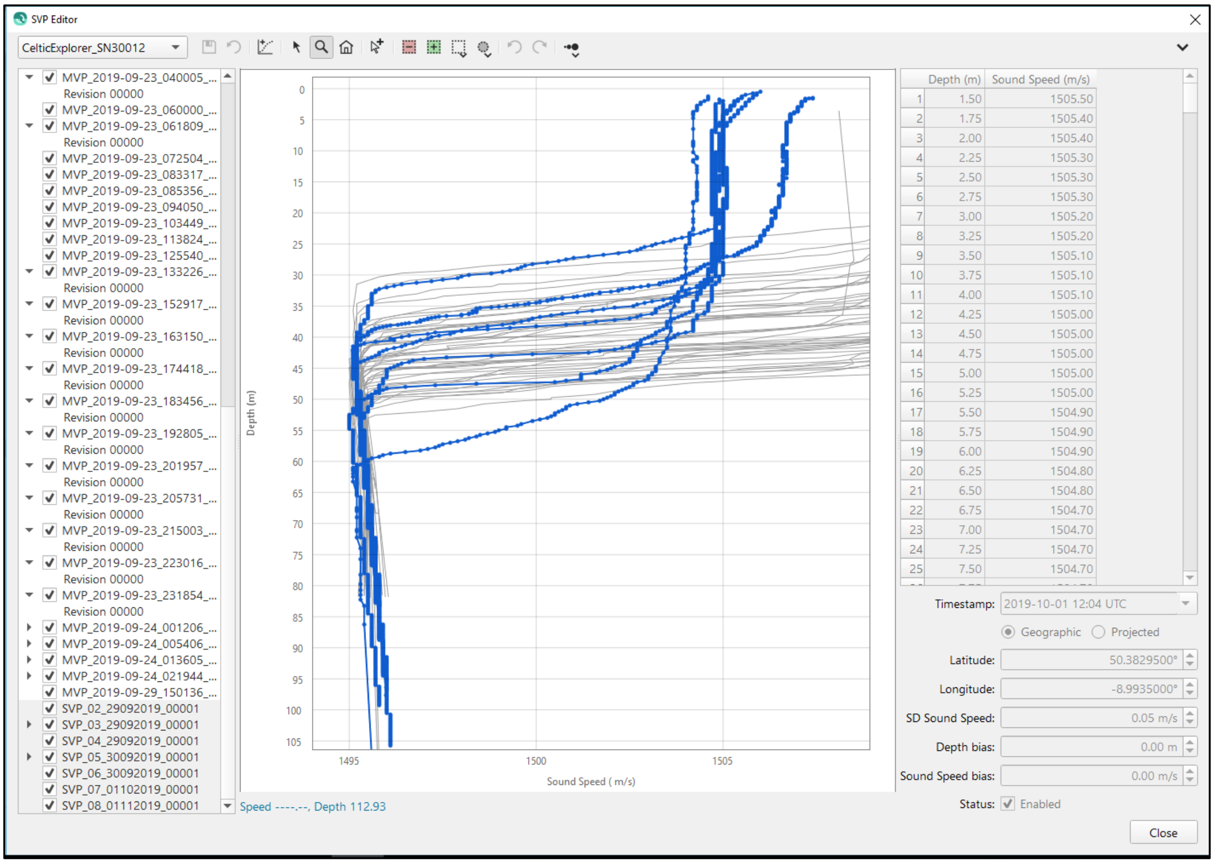


Figure 20: Plotted MVP & SVP casts.

4.2 Post Processing Methods

4.2.1 Navigation

Navigation data was logged in standard C-Nav format. The real time overall quality of the C-Nav positioning system is of high quality and meets IHO Order 1a standard. Vertical errors on the GPS heights are also low (+/- 20 cm) and provide a robust solution for computation of GPS tide.

Navigation data and in particular GPS heights were despiked and smoothed in Caris HIPS. GPS tide was computed using the separation model between International Terrestrial Reference Frame (ITRF) datum and VORF LAT.

4.2.2 Depth Soundings Data Processing

Soundings were edited in Caris HIPS and Qimera processing software against an existing chart background. Combinations of automated and manual processing procedures were applied by experienced data processors to remove systematic errors and obvious outliers. Uncertainty results were examined to ensure they fell within IHO specifications for Order 1a and Order 2 surveys. Processed and cleaned data were subjected to final validation by an experienced and qualified hydrographer. The following is a simplified list of steps undertaken during sounding data processing:

1. Navigation data were applied to survey data.
2. GPS tides were computed using the UKHO's VORF model. This reduced the MBES depth soundings to LAT. GPS tide results were then checked for quality and consistency.
3. TPU values were calculated.
4. SVP data were applied to correct for refraction errors caused by water column heterogeneity. A range of SV algorithms were used to determine the most suitable method of applying SV corrections, for example: nearest in distance versus nearest in time.
5. Qimera's "*TU Delft Sound Speed Inversion*" tool was used to correct refraction issues.
6. Subset Editing was performed in CARIS to clean large "noise" spikes from the data.
7. A CARIS Combined Uncertainty and Bathymetry Estimator (CUBE) base surface was then created to allow CUBE automatic filtering.
8. Final verification of sounding consistency and absence of spikes was carried out using subset editing.
9. Export of final products from Caris: Multibeam Bathymetry grids, Shaded Relief grids, and Backscatter Mosaics. XYZ and track line grids were output.

4.2.3 Backscatter Mosaic Generation

Backscatter is a function of the hardness and roughness of the seafloor. Raw multibeam backscatter data were analysed using QPS FMGT, a backscatter analysis software with advanced functionalities capable of providing an enhanced backscatter mosaic.

4.3 Survey Results and Data Interpretation

A preliminary interpretation of MBES and SBP data was used to assess bathymetry, seabed texture, seabed features, and shallow geology.

4.3.1 Multibeam Images

EM2040 data were used to produce final data products. Grids and geotiff images were created in Caris Hips software of EM2040 MBES bathymetry and shaded relief data. The backscatter mosaic grid was created in QPS FMGT software. Grids and images were imported into ArcGIS. Bathymetry and backscatter mosaic geotiffs were created in ArcGIS and are presented in figures 21 to 26 along with shaded relief geotiffs of both survey areas.

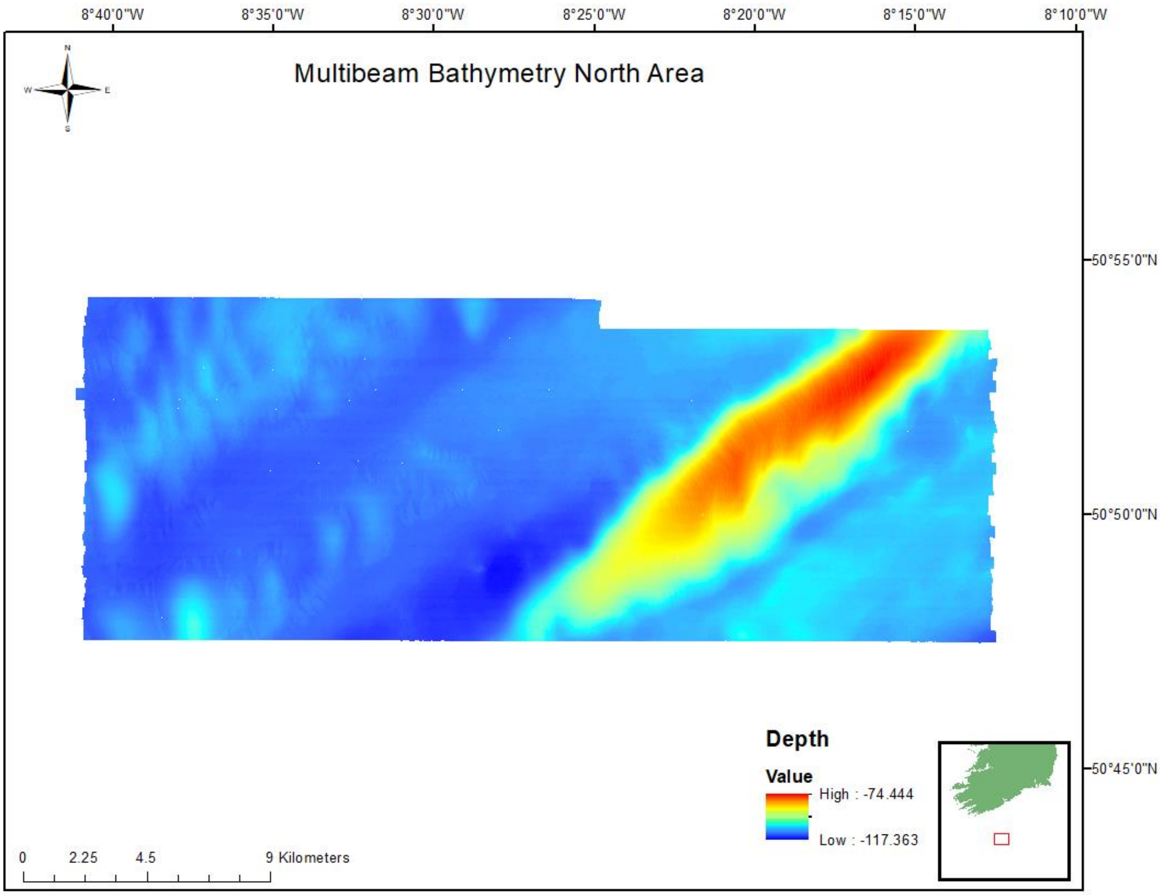


Figure 21: Multibeam bathymetry image north area.

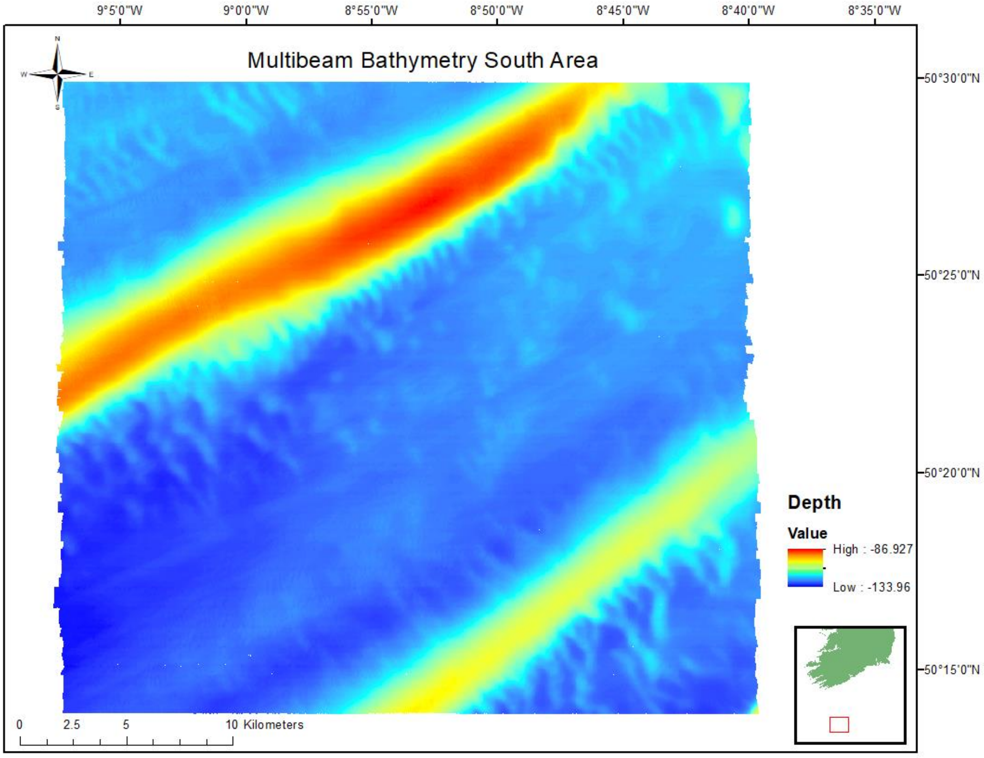


Figure 22: Multibeam bathymetry image south area.

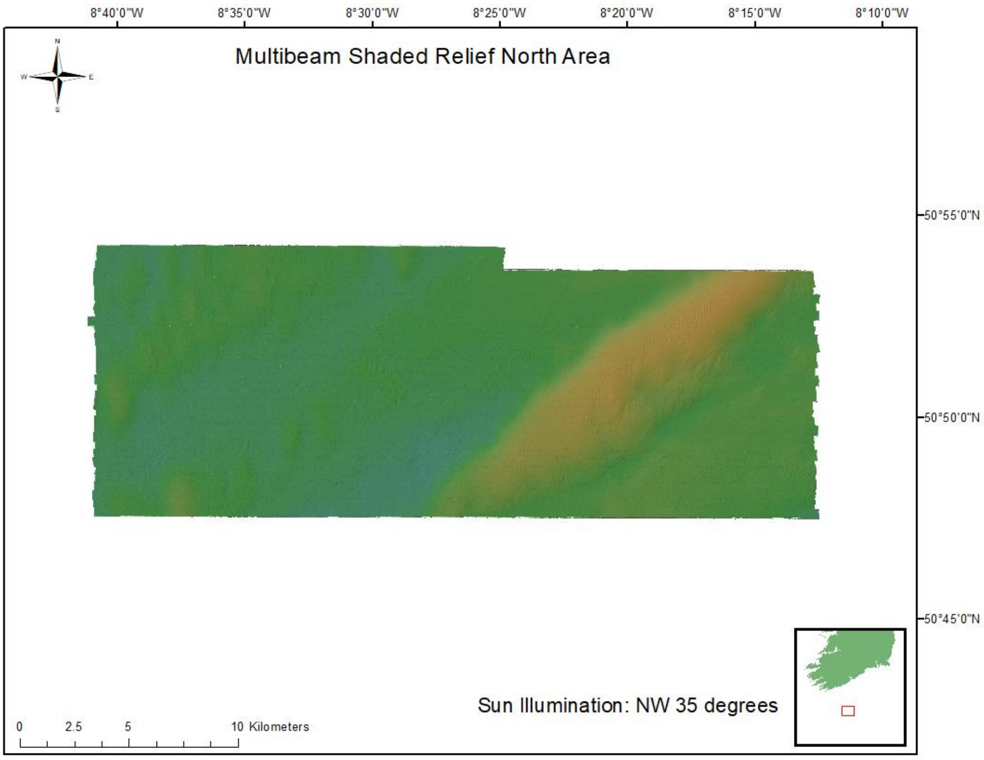


Figure 23: Multibeam shaded relief image north area.

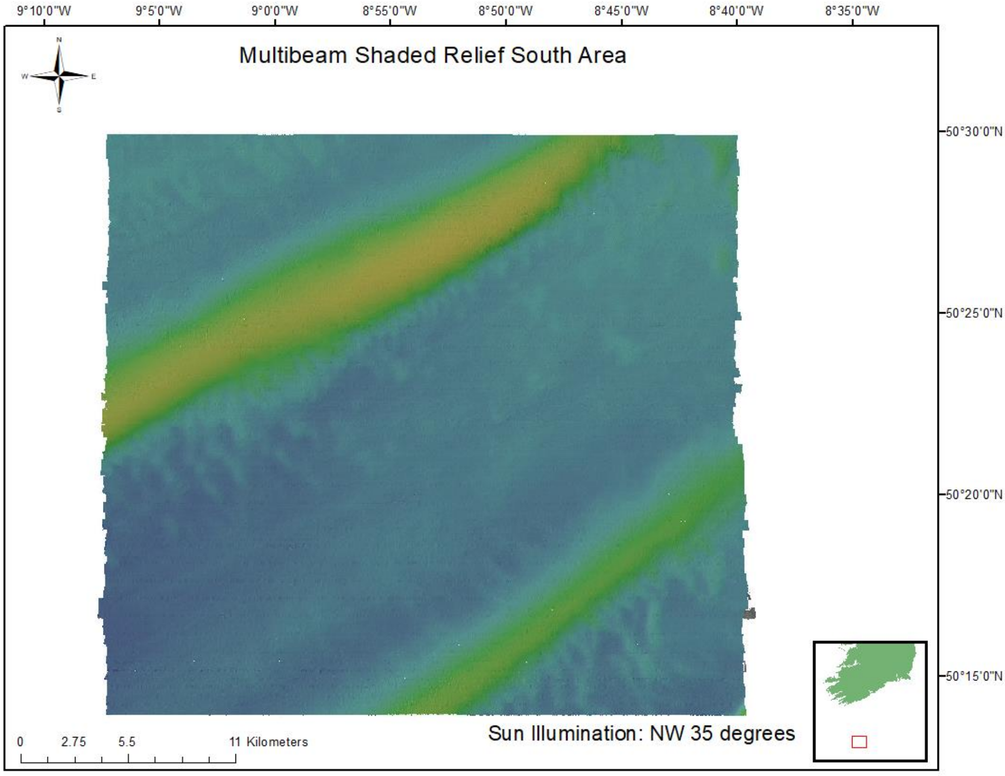


Figure 24: Multibeam shaded relief image north area.

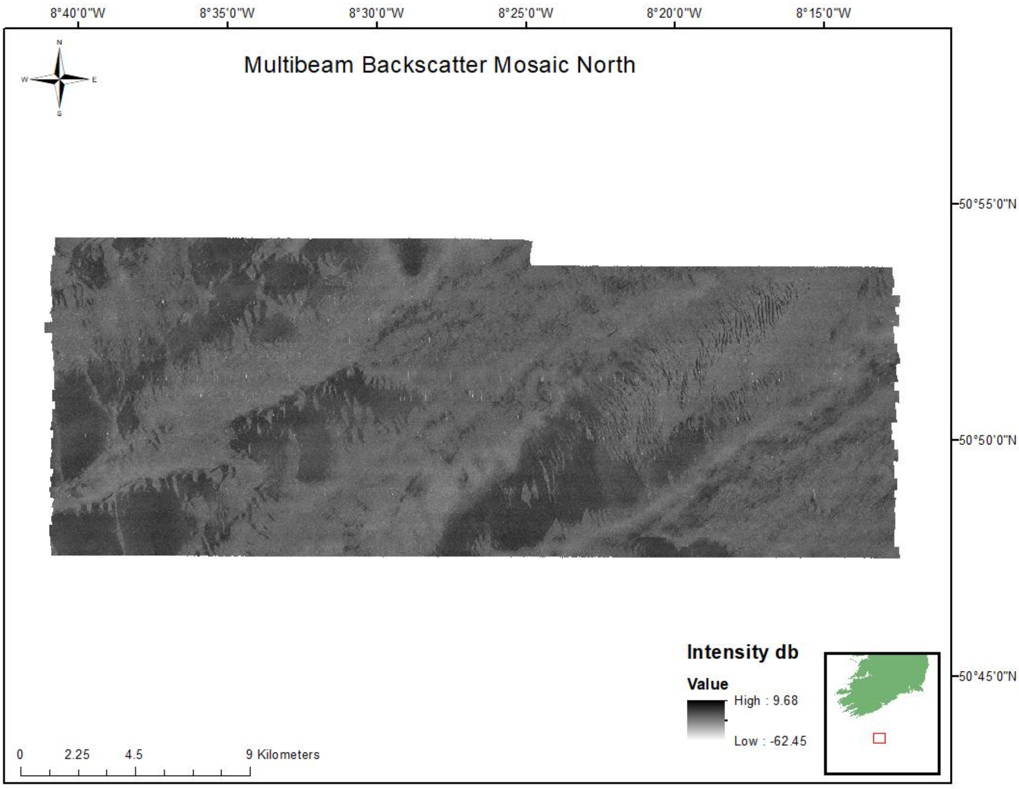


Figure 25: Multibeam backscatter mosaic image north area.

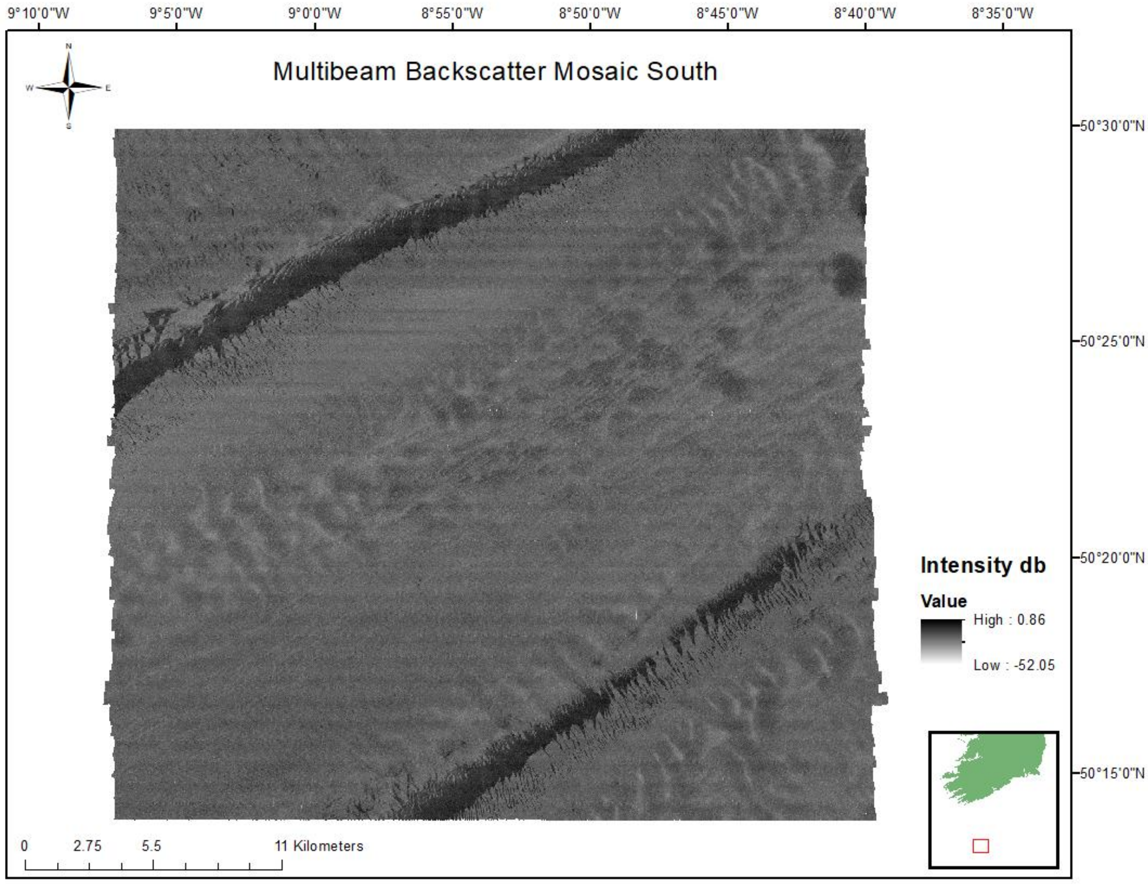


Figure 26: Multibeam backscatter mosaic image south area.

4.3.2 Shallow Geology Analysis

Data quality and penetration varied depending on prevailing sea state, survey direction and sub-bottom hardness. Survey speed (4-9 knots) was dictated by MBES data quality and weather conditions. Good quality MBES data can be acquired at speeds that compromise sub bottom profiler data integrity. SBP data was generally of good quality although a very hard substrate in places prevented signal penetration. IxBlue have worked on a technical solution to heave correct the SBP data in post processing and the data presented here illustrate this solution. Heave corrected data was not previously available. Profiles show in this report have TVG, AGC, heave correction and stacking applied.

Figure 27 shows the track lines for four SBP lines selected for analysis in this report. Selected profiles are from the south area. The track lines are overlain on multibeam bathymetry. Line 149 does not show the full extent of the profile due to a glitch in the navigation file. It is actually nearly 24 km in length as seen in figure 29.

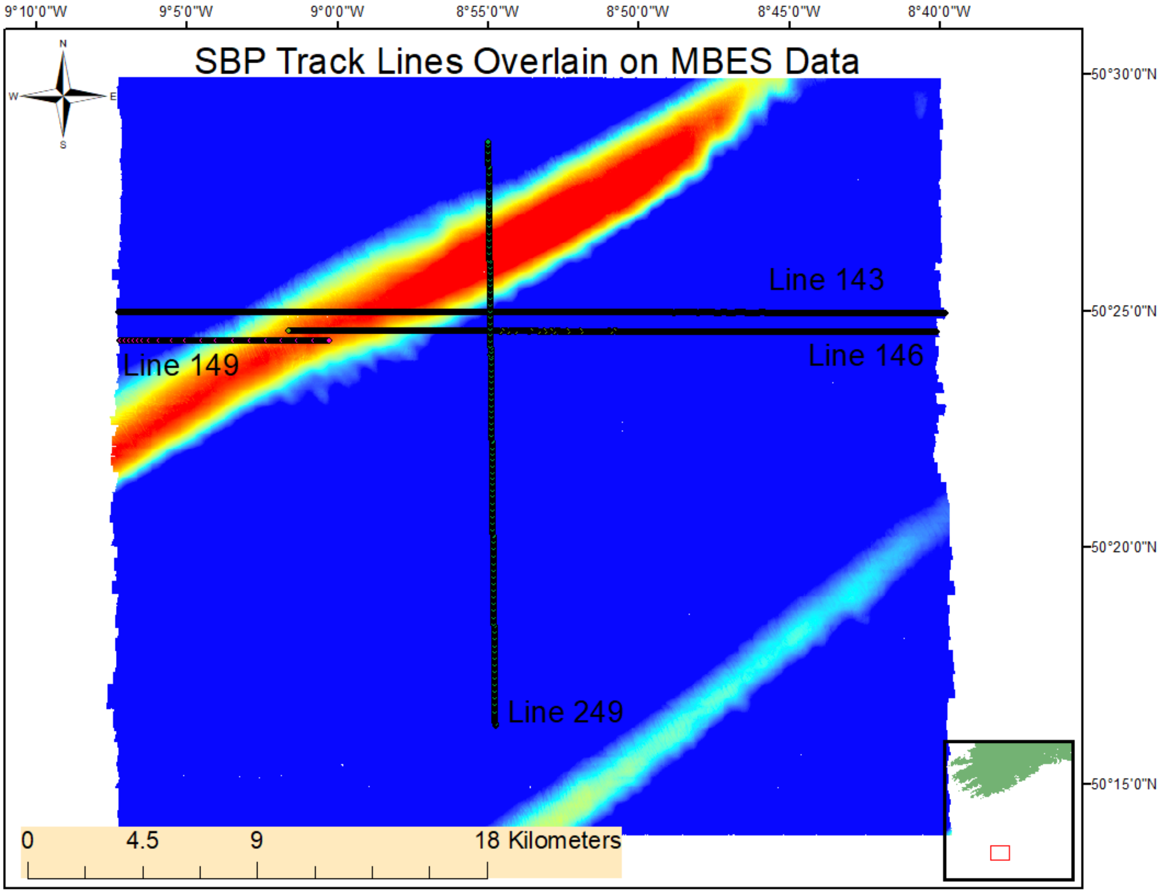


Figure 27: Multibeam bathymetry with sub bottom profiler interpreted tracklines.

Profile 143

Figure 28 shows SBP line 143. The profile was acquired on a westerly heading. Vertical scale lines are at 10 metre intervals and the total horizontal extent is 31.6 km. The seabed topography is dominated by a large ridge, over 30 m in amplitude at the western end of the profile. The ridge is approximately 9 km in width. Its eastern flank has a rib feature, approx. 5 m in height at the ridge base. The western flank is dominant by small waveform labelled as crenulations in figure 27.

Three distinct sedimentary units are identified. The base unit, annotated as Unit 3 appears to be present across the entire profile. Unit 3 has no internal reflectors. The top of this unit is denoted by an unconformity surface, Horizon 2. Horizon 2 is not evident beneath the ridge. It is probable that poor signal penetration beneath the ridge prevents its lateral traceability. Unit 2 unconformably overlies Unit 3. Unit 2 has a maximum thickness of 10 metres. It has several internal reflectors although these are not laterally traceable for long distances. The top of Unit 2 is denoted by Horizon 1. Horizon 1 can be widely traced to the east of the ridge. It is overlain by Unit 1. Unit 1 is a thin unconsolidated unit with a maximum thickness of approx. 3 metres. None of these units or horizons are observed beneath the ridge and Unit 1 is not observed on the western side of the ridge.

Profile 146

Profile line 146 (figure 29) is located approximately south of profile 143 and is also orientated east-west. The profile is 25 km in length. The sub-bottom interpretation is similar to that of profile 143. The rib feature is also present of the eastern ridge flank. Unit 3 is the base unit. Unit 2 overlies to the east of the ridge and is up to 12 metres in thickness. Unit 1 is found in pockets less than 3 metres in thickness.

Profile 149

Profile 149 (figure 30) is located south of Profile 146. It is orientated west-east and is almost 24 km in length. The sub-bottom geology is similar to the above profiles with a few differences; Unit 1 is thicker on this profile, up to a maximum of almost 10 metres. There are 3 distinct ribs on profile 149 on the eastern flank of the ridge. Crenulations on the western ridge flank are more pronounced and span a greater area than on the other profiles.

Profile 249

Profile 249 (figure 31) is a crossline that crosses all three of the interpreted profiles. It is orientated south-north and is 23 km in length. The sub-bottom geology is similar to the above profiles, with all sedimentary units present along with the ridge, rib and crenulations. No horizon interpretation has been done on this profile to provide an unhindered view of the seabed and seismic reflectors.

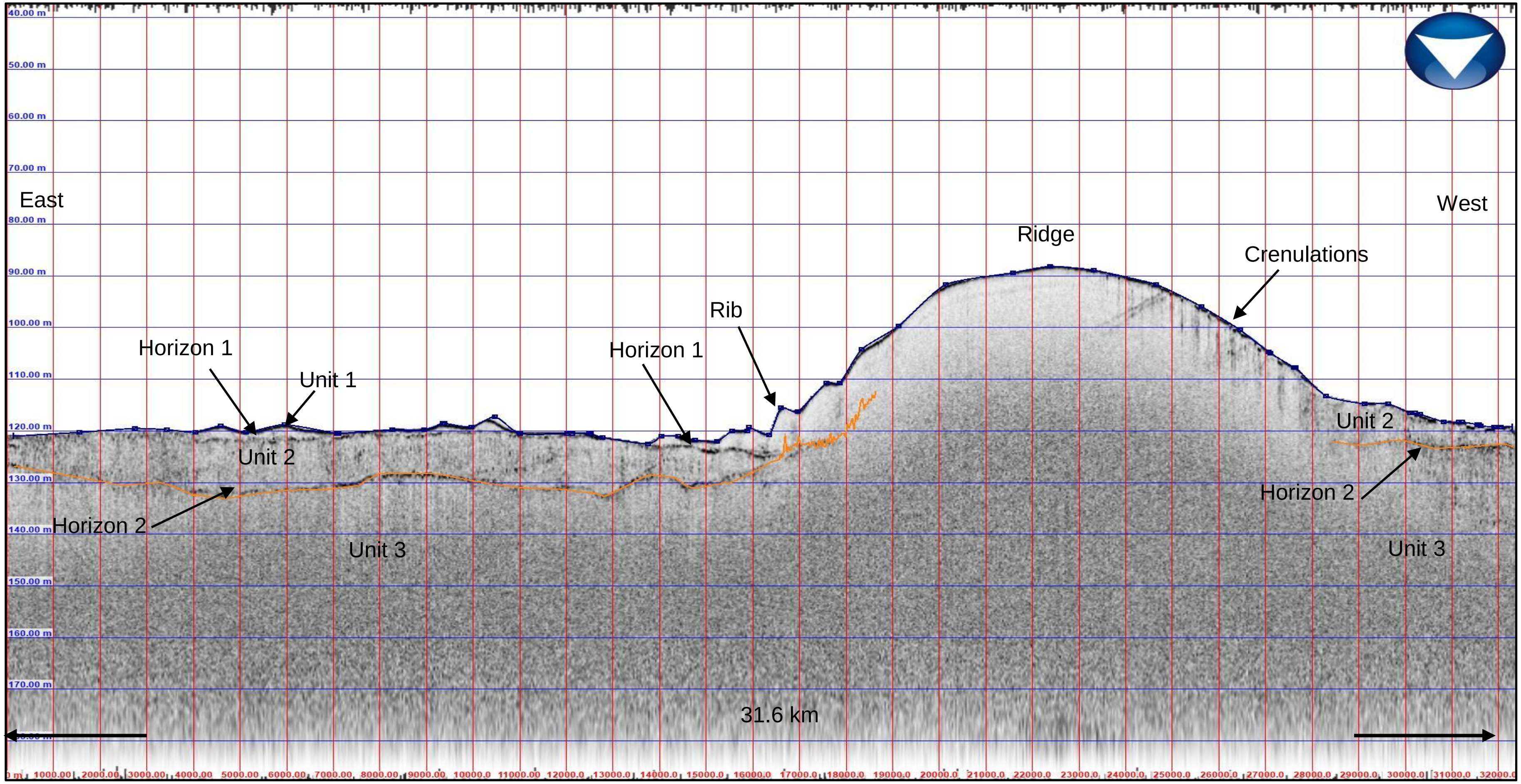


Figure 28: Sub bottom profiler data, line 143.

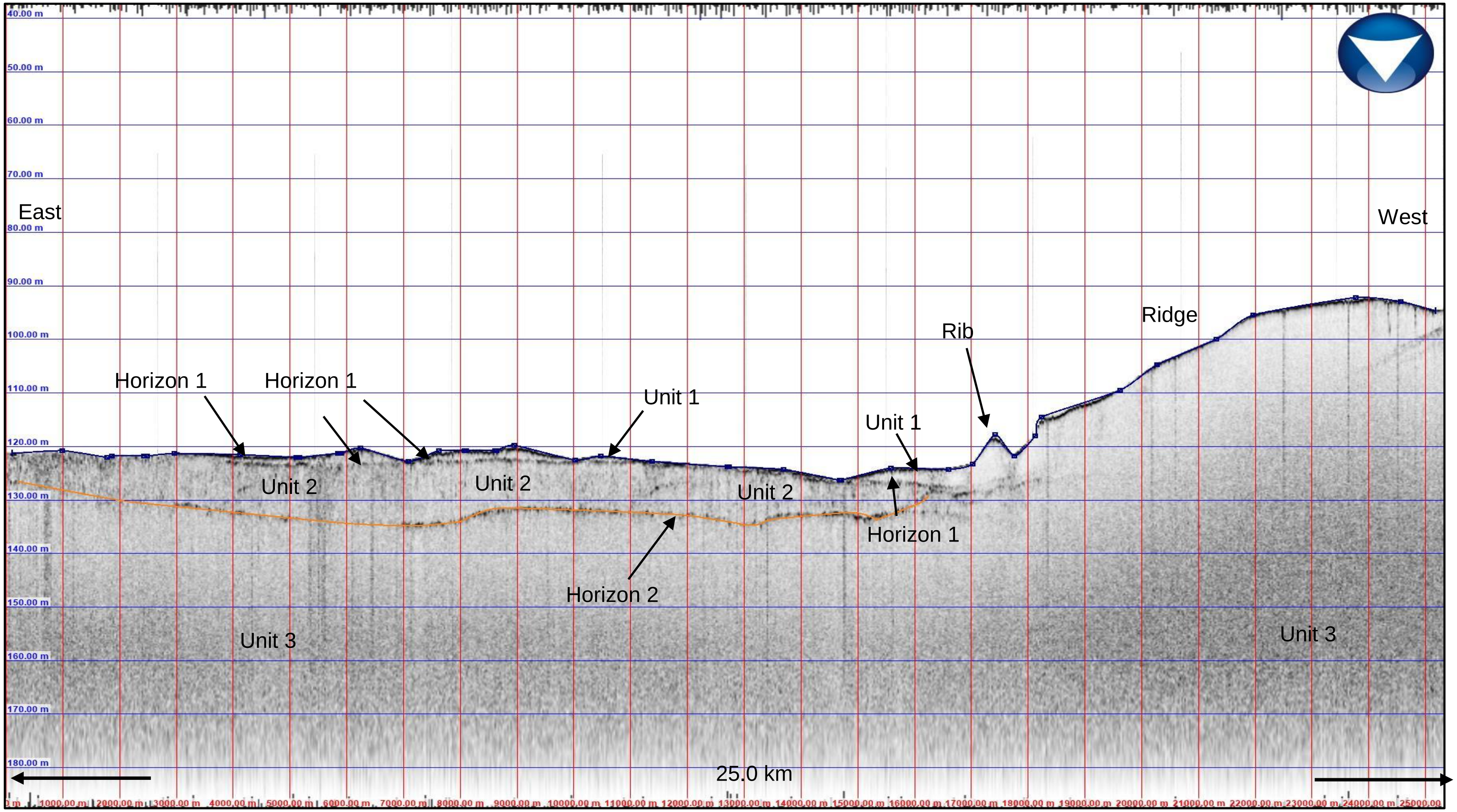


Figure 29: Sub bottom profiler data, line 146.

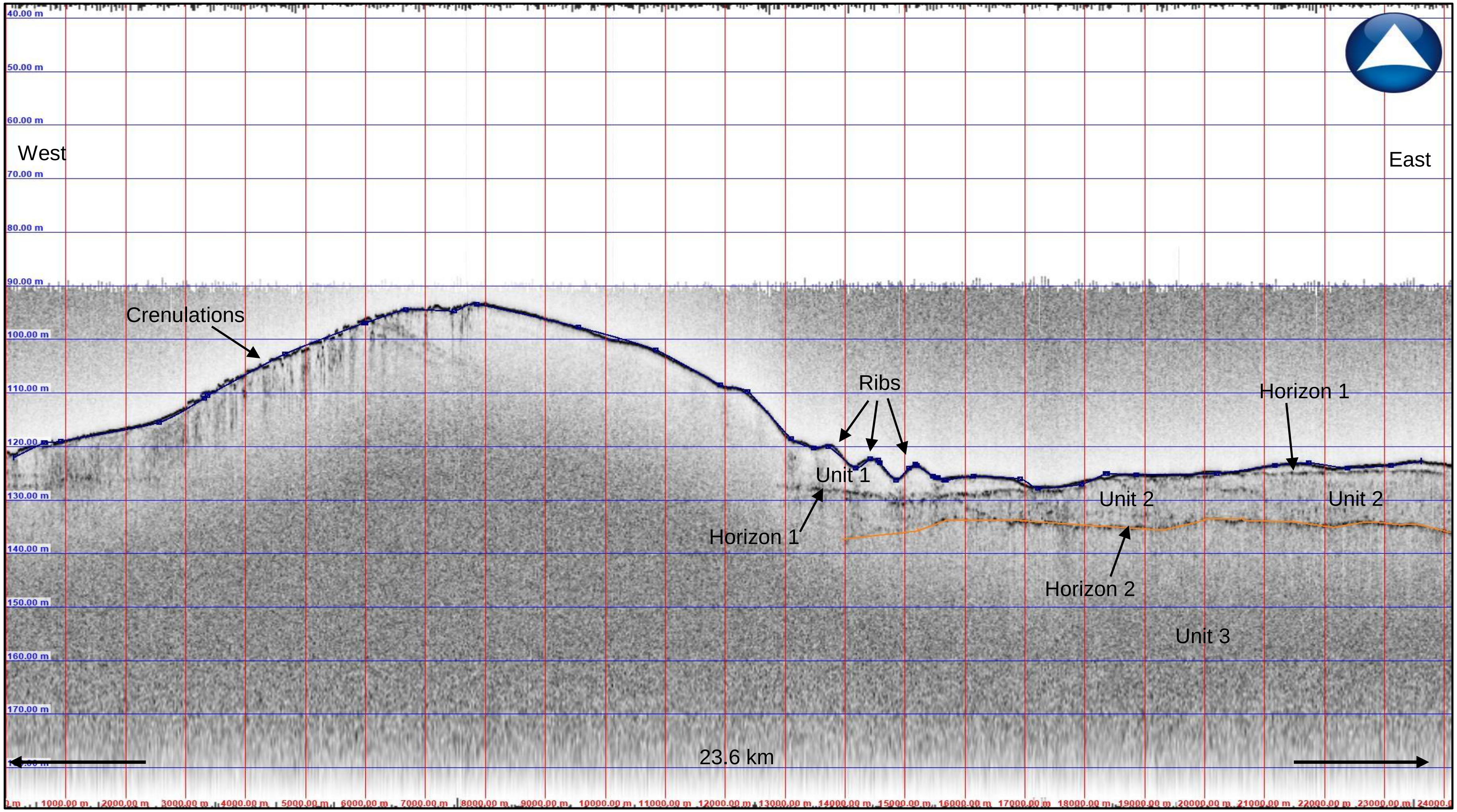


Figure 30: Sub bottom profiler data, line 149.

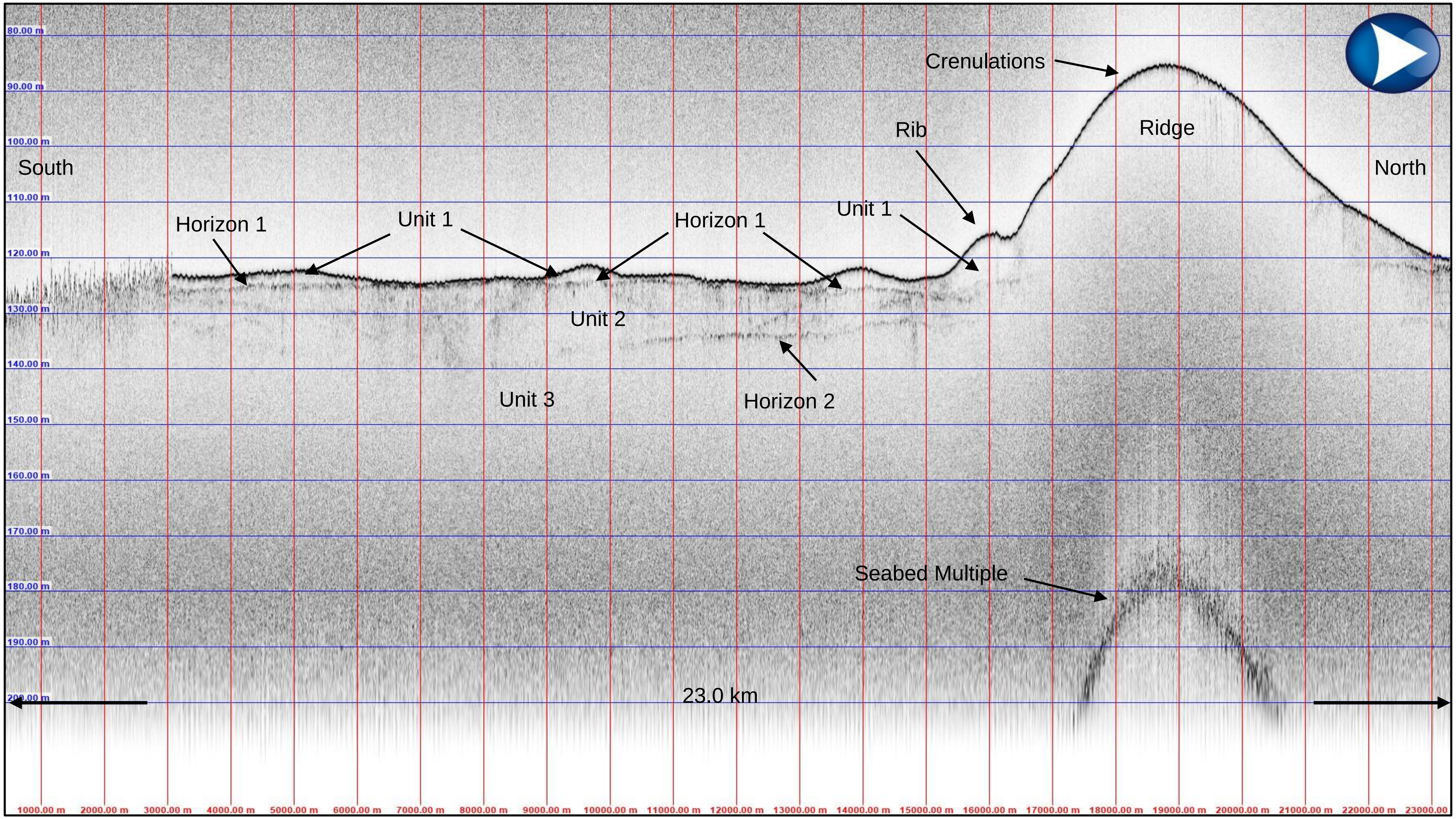


Figure 31: Sub bottom profiler data, line 249.

4.3.3 Bathymetry

An overview bathymetry image, gridded at 5 m is presented in figure 32. Water depth varies from 74 to 117 metres in the north area and 87 to 134 metres in the south area. A series of large-scale ridges dominate the bathymetry of both areas. They are orientated along a north-east to south-west trend, which is typical for these types of ridges in this part of the Celtic Sea.

The ridge in the north area is between 25 and 30 m in amplitude and up to 3 km in width. The largest ridge in the south area is 30 m in amplitude, 3.5 km in width and 29 km in length within the surveyed area.

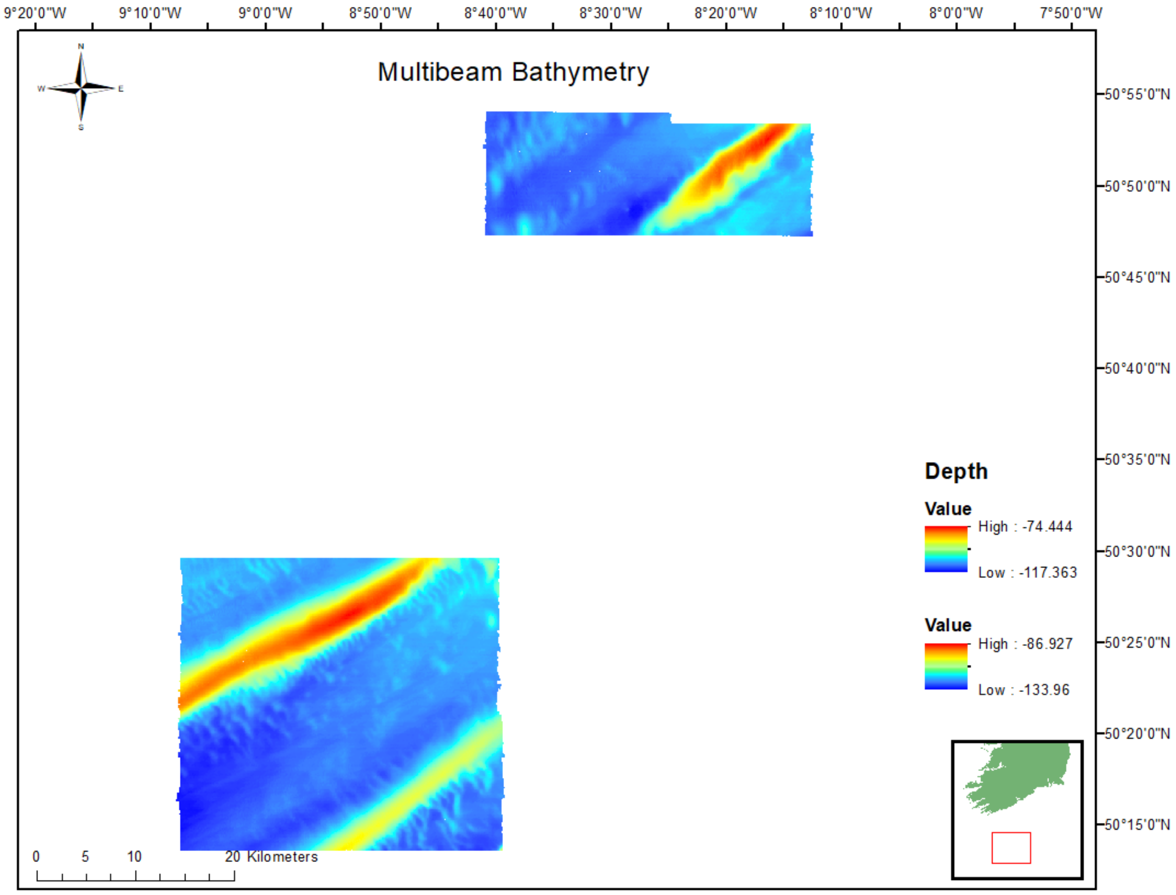


Figure 32: Multibeam bathymetry overview.

Figure 33 is an image of part of the largest ridge in the south area. The ridge crest is characterised by transverse bedforms which are generally less than 100 metres in width and 1 metre in relief. The features are bathymetric lows where sediment has been scoured.

Correlation with backscatter indicates that these features are comprise sediments of higher relative backscatter intensity than the surrounding sediments.

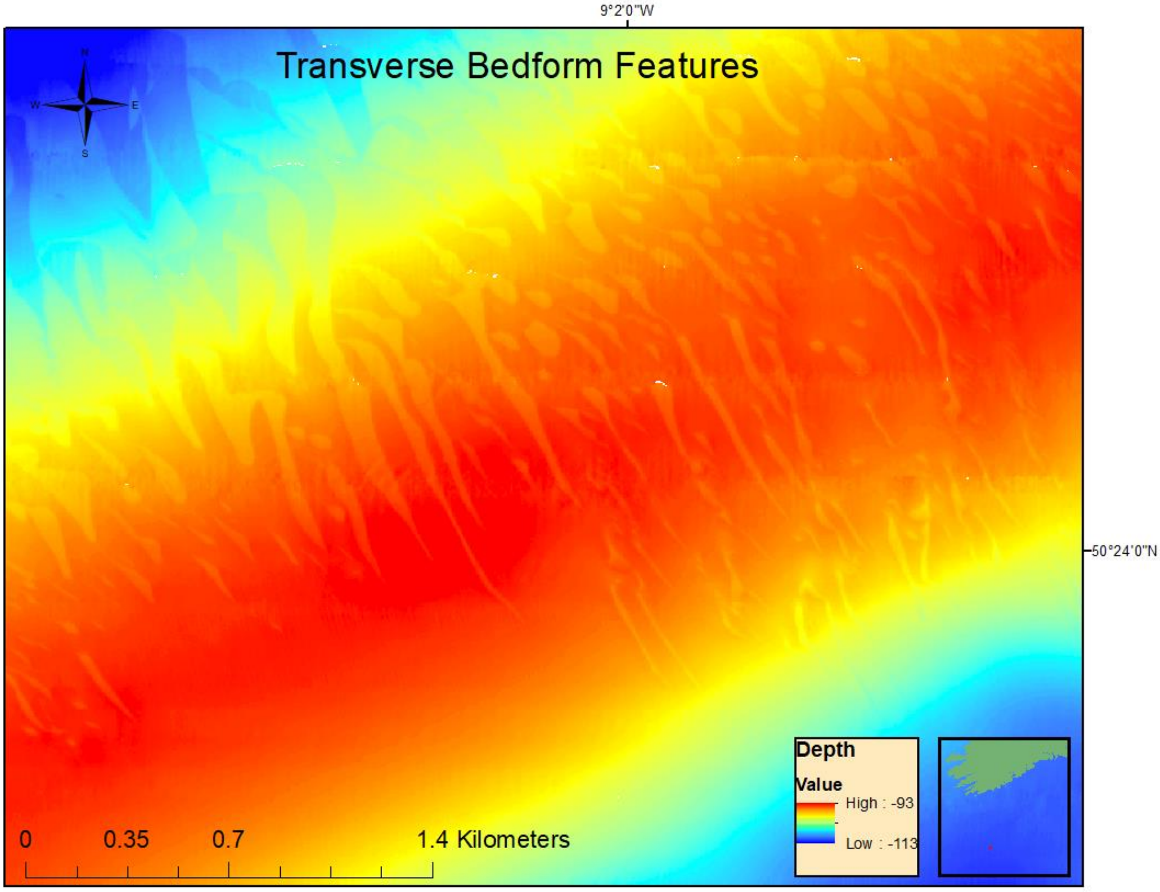


Figure 33: Multibeam bathymetry of south area ridge.

4.3.4 Seabed Texture

Multibeam backscatter is the amount of acoustic energy being received by the sonar after a complex interaction with the seafloor. Analysing the amplitude of the returning sound waves enables us to extract information about substrate structure and hardness, allowing for identification of substrate types. Seabed reflectivity properties depend on the hardness and roughness of the seafloor surface. In simple terms a strong return signal indicates a hard and/or rough surface and a weak return signal indicates a soft, smooth surface.

EM2040 multibeam data was used to produce backscatter images in this report. EM302 backscatter data was also acquired. Figure 34 shows a subset of the backscatter mosaic for the north area. The convention used is that dark coloured areas represent relatively higher intensity (stronger) returns than light coloured areas. This image corresponds with a ridge crest which is oriented NW-SW. The high intensity backscatter slivers are almost at right angles to the ridge crest. They are up to 100 m in width and 2 km in length, have a sinuous character and sometimes bifurcate. Their relative backscatter intensity sharply contrasts with the surrounding sediments. Analysis of bathymetry data shows that the high backscatter slivers are bathymetric lows. Backscatter and bathymetry data combined indicate that these slivers are scoured substrate.

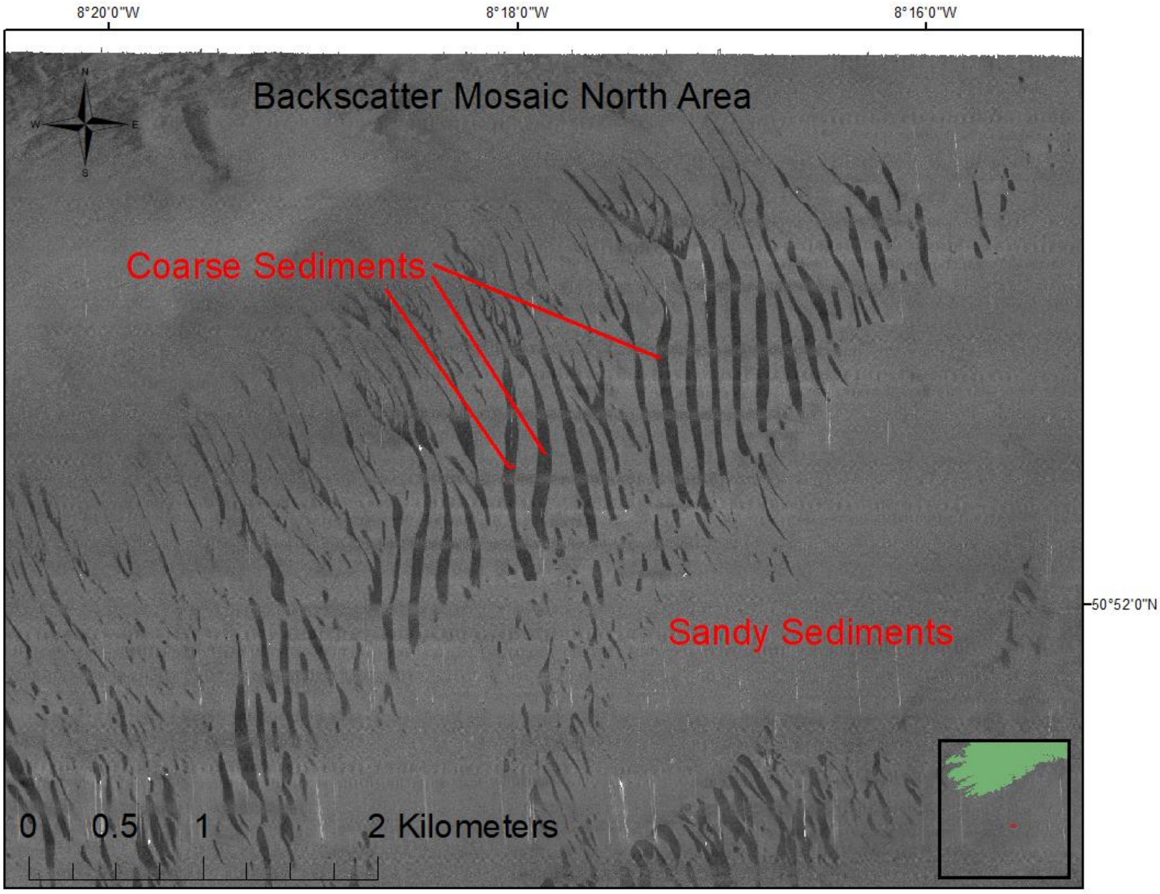


Figure 34: Backscatter mosaic, subset of north area.

Figure 35 shows backscatter mosaic data from a subset of the south area. A distinct NE-SW orientated area of relatively high backscatter returns is evident. This linear area is approximately 1 km in width and is located at depths of approximately of between 114 to 119 m. It is situated to the NW of the ridge crest and run parallel to the crest itself. Correlation with SBP data shows that the feature corresponds with Unit 2 of the sub-bottom interpretation. Sediments of much lower relative backscatter are found on the ridge crest. These linear areas of relatively high backscatter situated to the NW of adjacent ridge features compromising much lower backscatter type sediments are characteristic of this part of the Celtic Sea.

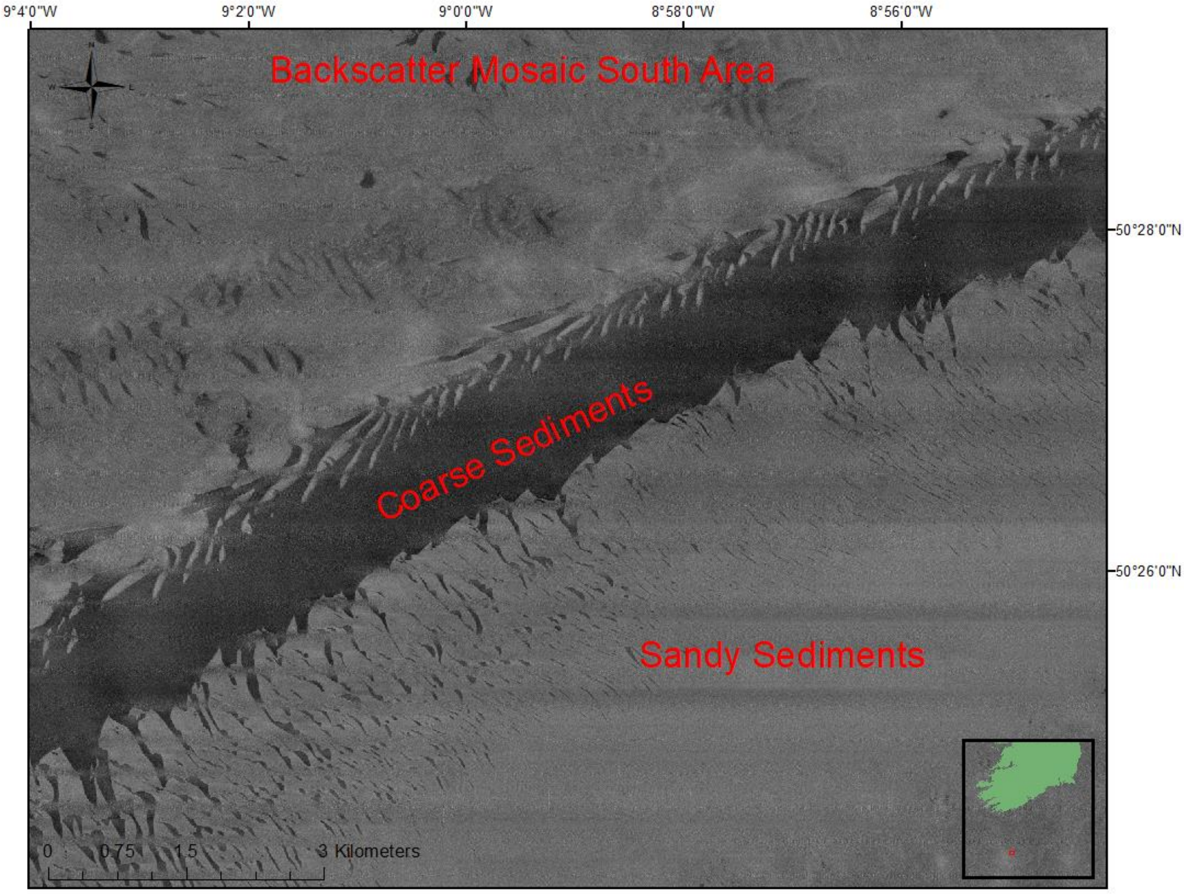


Figure 35: Bathymetry mosaic, subset of south area.

4.3.5 Seabed Features

Description of seabed features is based on analysis of bathymetric, shaded relief and backscatter data. It is possible to make valid inferences on seabed character and composition by correlating these datasets. Shaded relief data is used to illustrate the features discussed in this section. Shaded relief imagery is produced in Caris by shining an imaginary sun at 35º angle over the depth colour coded multibeam bathymetry dataset.

Figure 36 is an interpreted shaded relief image of part of the north area. Sun illumination is from the NW. It shows a ridge crest cut by erosional scours (of high relative backscatter intensity in section 4.3.4). A scar is located to the south of the ridge crest. Relief across this scare is less than 2 metres but it is clearly defined lineament. The scar is marked by a change in backscatter from low to high (see backscatter image, figure 25) as one moves SE across the feature. This correlates with an increase in water depth across the scar but the depth changes are less than 2 metres.

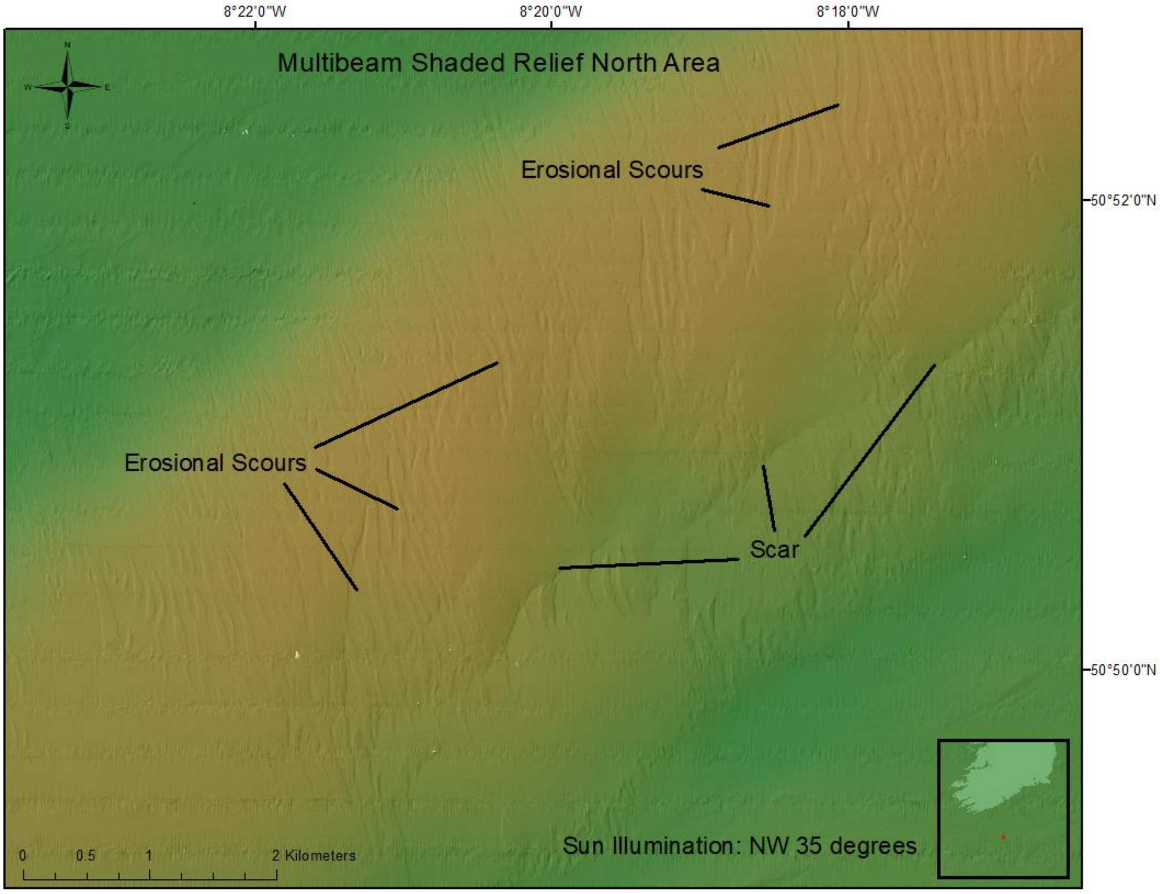


Figure 36: Multibeam shaded relief features, north area.

4.4 Groundtruthing

Groundtruthing was not undertaken during this survey due to persistently unfavourable weather conditions. Future surveys will groundtruth this area.

4.5 Wrecks

Six wreck sites were identified from multibeam and magnetometer data and detailed wreck surveys were completed. Table 19 lists the wreck metadata.

Number	Length / m	Name	Latitude	Longitude
1	115	Unknown	50.27889º N	-8.72597º W
2	84	Unknown	50.26787º N	-8.99890º W
3	117	Unknown	50.2360º N	-8.92808º W

4	61	Unknown	50.26244º N	-8.91167º W
5	64	Unknown	50.47804º N	-8.92699º W
6	120	Unknown	50.48427º N	-8.86402º W

Table 19: Wreck metadata.

Figure 37 shows the location of the mapped wrecks overlain on the multibeam backscatter data. The wrecks are unidentified at the time of writing.

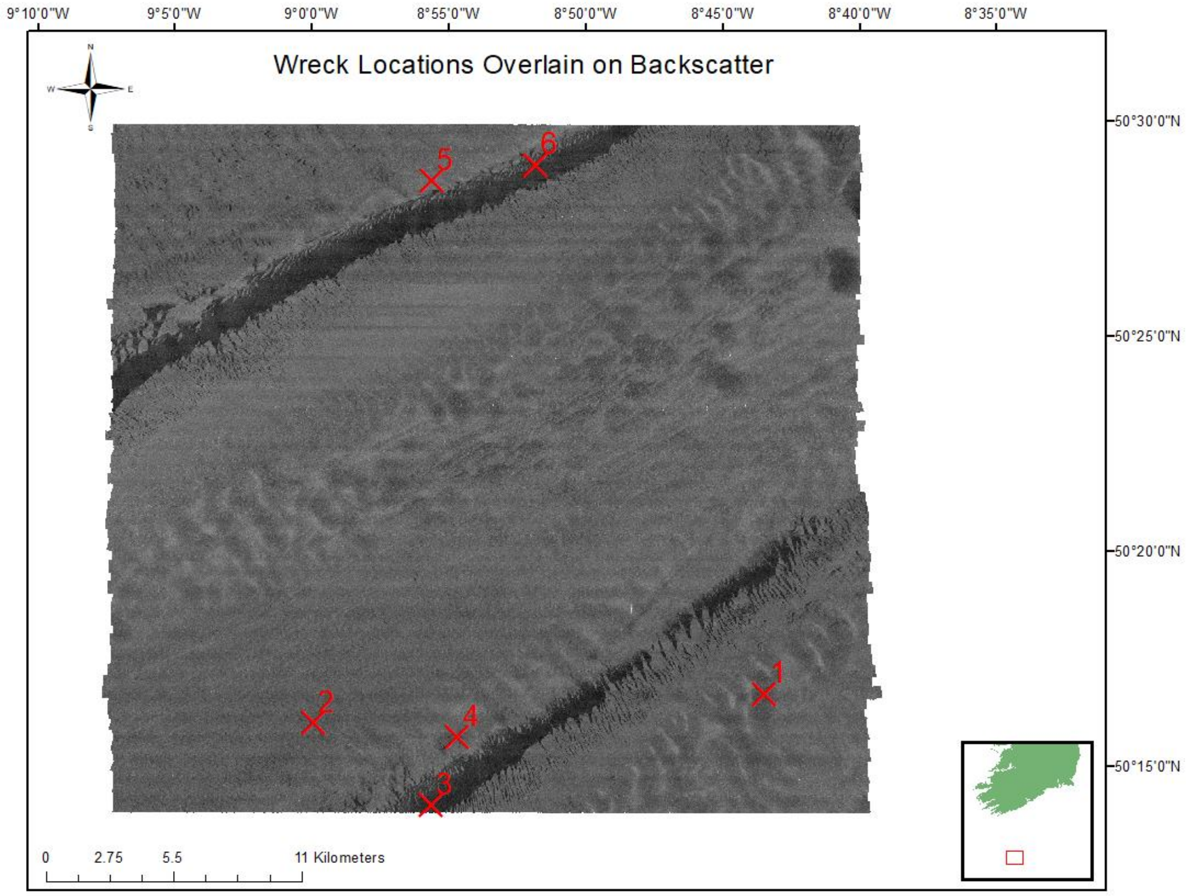


Figure 37: Mapped wrecks overlain on bathymetry.

Figure 38 shows an image of wreck 1. It is located on a flat substrate and is 115 metres length. The wreck has undergone extensive decay.

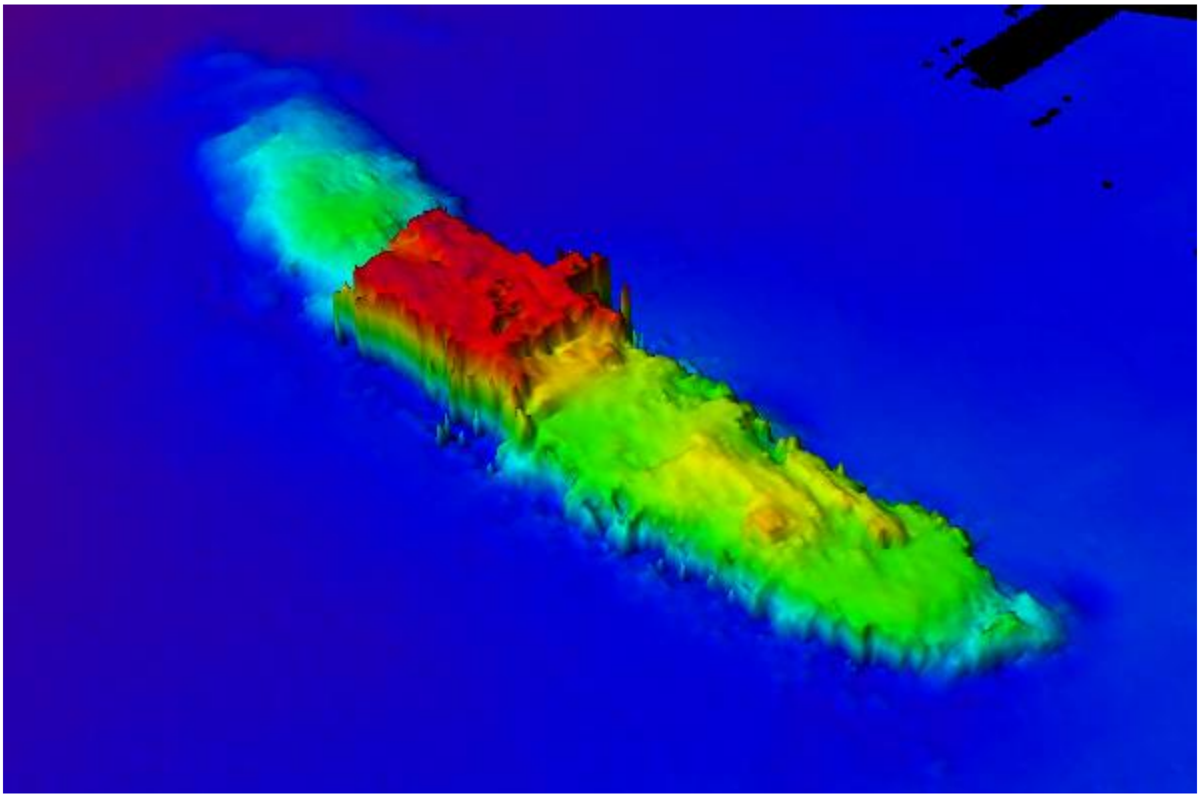


Figure 38: Unidentified wreck 1.